



UNIT 1 SCIENCE AND THE PLANET EARTH

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The drawing on the front cover is from Copernicus's original manuscript, and places the Sun at the centre of the Universe.

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STUDY GUIDE

This Unit consists of three components: the text, the associated experiments, and the TV programme 'The planet Earth — a scientific model'. You will find notes relating to this TV programme at the end of the text.

We are conscious that you may not have studied for some time. So, as this is the *first* Unit of the Course, we shall take up somewhat more space with this Study Guide than will be normal in later Units, in order to offer some specific advice on how to tackle this and other Units. More general advice on how to study is given in the *Introduction and Guide*, which you should by now have read carefully.

The text You should read the text thoroughly — it is the core of the Unit. In order to help you to assimilate this material, we have provided plenty of questions for you to answer along the way. There are two formal types of question — In-Text Questions (ITQs), and Self-Assessment Questions (SAQs). ITQs are specifically designed to carry the argument forward, so you should always do such questions *when you come to them*, and then refer to their answers before you move on. SAQs, on the other hand, are designed to help you to consolidate ideas that you have already met; they enable you to assess for yourself whether you have understood the main terms and concepts introduced in the Unit, and whether you have mastered the particular skills or techniques listed in the Objectives for the Unit. These Objectives, together with the answers for both the ITQs and SAQs, are to be found at the end of the Unit.

Whereas most of the Unit is about the relative motion of the Sun, Earth and Moon, Section 1 comments briefly on the nature of science and its methods. Certain important terms, such as model, that recur throughout the Course are introduced here. This material will have its proper impact only when you have become familiar with some concrete science which illustrates the general points that it is trying to make. We recommend you to read quite quickly to the end of Section 1.2.1 and then, when you have read all the way through the Unit, to reread Sections 1.2 and 1.2.1 in conjunction with the concluding remarks of Section 6.

Experiments Two simple but important experiments are integrated into the Unit in Sections 3.5.2 and 4.1.2. To do them, you will need: three or four metres of thin string; two small heavy objects that can be hung from the string (e.g. good-sized bunches of keys); and a watch that can measure seconds. When you come to these experiments, you may think you know the result you will obtain; but be careful, you may well be in for some surprises. You should certainly not be tempted to skip these experiments, for they are carefully designed to carry the argument of the text forward; omitting them may well hinder your understanding of the subsequent text. Also, they are an important component of the week's work and may well be assessed in the associated Computer-Marked Assignment (CMA).

TV programme, 'The planet Earth — a scientific model' This programme is designed to reinforce your understanding of several of the ideas presented in the text. In particular, it discusses the following in more detail: the Foucault pendulum experiment and its contribution towards our knowledge of the Earth's spin; the phases of the Moon and how they relate to the motion of the Moon about the Earth; and the apparent reversals in the progression of the planets across the sky. In order to derive maximum benefit from this programme you should already have read through the text at least once before the programme is transmitted. (Note, however, that this is *not* a general rule. It will sometimes be possible, and even desirable, for you to watch a TV programme before, or perhaps during, your first reading of the associated text.) You will probably find it helpful to read through the introductory paragraph of the TV Notes (Section 5) *before* watching the programme; it will give you an indication of what to expect. Read through the rest of the notes when you have watched the programme, to help you consolidate what you have learnt.

If you complete this Unit ahead of schedule (well, all things are possible!), we suggest that you move straight on to Unit 2. There is a logical continuity between the Units that makes this the natural thing to do. But there is also the point that, whereas Unit 1 concentrates on qualitative concepts and the visualization of scientific models, Unit 2 begins to ask *quantitative* questions, such as 'how big?' and 'how far?'. If your mathematics is at all rusty, you should try to allow yourself as much time for Unit 2 as possible.

Finally, if you have not already done so, we suggest that you now obtain as many items as you can from the shopping list in the *Introduction and Guide*; this will save much time and inconvenience later in the Course when you come to do the various experiments. In addition to the items that you will need for this Unit's experiments (see above), the most urgent things to obtain are the ones you will need for Units 2 and 3:

a piece of straight dowelling at least 1.2 metres long (a broom handle would do nicely!);
 a tape-measure or rule (with centimetre and millimetre markings) at least 1.5 metres long;
 some Blu-Tack or plasticine;
 a pair of compasses and a sharp pencil;
 a protractor.

I INTRODUCTION: SCIENCE IN PERSPECTIVE

'The whole of science is nothing more than a refinement of everyday thinking.'
 (Einstein, *Physics and Reality*, 1936)

You might expect a science foundation course to start with a simple definition of science, but this is not easily done. The problem is that science is a very complicated business, and it can be looked at from a variety of angles. When people look at something complicated from different directions, they see different things. So all that we shall do at first is to sketch the view from two popular standpoints. As you work your way through the Course, you may find that these perspectives are a useful way of framing what you have learnt.

Look at the photograph of the planet Earth in Figure 1. It was taken in 1968 from a satellite at a range of about 38 000 km (24 000 miles). When they look at such a photograph, some people think first of its cost, and ask whether it was worth all the money and effort of sending up a satellite. Here, science is viewed from a *social* standpoint. The photograph was not the work of an isolated individual, but of a complex industrial society with considerable technical skills. The satellite from which the photograph was taken was the work of many hands. The calculations that put it in the right place had been developed by generations of scientists. And finally, the decision to undertake the enterprise was a political one: it involved the postponement of other social and scientific projects which were assigned a lower priority.

Other people might find this photograph attractive because of its romantic associations with space travel. Few people were not moved by the thought of fellow human beings drifting about in space and (later) walking on the Moon. There is no doubt that human curiosity is the most elemental, most basic driving force behind science. For many of us, questions such as 'What does the dark side of the Moon look like?' or 'What is it like on the Moon's surface?' have an irresistible appeal. In this particular case, the photograph is, for many people, direct proof that the Earth is round. Seeing, it seems, is



FIGURE 1 The planet Earth. A black-and-white copy of a NASA photograph taken on 21 January 1968 from satellite ATS 3.

believing. Yet it has been known for centuries that the Earth is round, although nobody could actually *see* it until space travel became possible. The evidence of direct observation has a more powerful impact than conclusions reached by reasoning.

These feelings of curiosity and different degrees of conviction are the experiences of individuals, and they differ from the social matters discussed earlier. They are concerned with how we get to know things. Questions of this sort are raised when we examine the methods of scientific inquiry, the ways in which scientists make their discoveries.

The aim of science, then, is to understand the working of the natural world about us. We shall now comment further on science as a social activity, and then discuss how science is practised.

1.1 SCIENCE AS A SOCIAL ACTIVITY

When we speak of science as a social activity, the society that we first think of is the whole complex of social, economic and industrial relationships within which we live. Science influences the structure and the demands of this society, and society returns the compliment. An example of this mutual interaction is the development of nuclear energy. Nuclear fission — the breaking up of the tiny nuclei that are at the cores of atoms — was discovered almost accidentally by Otto Hahn and Fritz Strassman in 1938. This scientific finding very quickly had a profound effect on society. The perspectives and conduct of prominent social activities such as war and electricity production were radically changed by the development of nuclear weapons and nuclear power-stations. To obtain these things, society had to make demands on scientists, and to allocate the necessary resources. Consequently, both during and after World War 2, the work of thousands of scientists was focused on nuclear physics, and in particular on the study of uranium, plutonium and related chemical substances. This had a very important influence on the directions taken by post-war physics and chemistry.

An important intermediary in the mutual influence of science and society is technology. Science first raised the prospect of nuclear energy; but the practical implementation of it called for high-grade engineering skills. For example, new methods had to be designed to handle, machine and produce novel metals and alloys on a large scale. This illustrates how the development of science and technology in modern industrial societies is influenced by political and economic decisions on expenditure and investment. It is always worth considering whether the money is being wisely spent.

FALSIFIABILITY CRITERION

Now let us turn to science in the context of a more modest society: the society of scientists themselves. Science after all is the outcome of the combined efforts of this social group. Many interesting matters might be raised about the way the group functions: how they referee one another's publications, publishing some and rejecting others; how they set up committees; and how such committees dispense research money and award Nobel Prizes. However, here we shall concentrate on a common moral assumption that the members of the group share: when scientists read of one another's experiments or calculations, they assume that they are reading a truthful account, written in good faith. This mutual trust allows scientists to benefit from one another's work. Without it, the development of science would have been abysmally slow.

The importance of the assumption of truthfulness is shown by scientific attempts to investigate 'paranormal' phenomena such as telepathy or spoon-bending (Figure 2). It is not that there is nothing of scientific interest here — the problem is that the investigator and the investigated *may* not be engaged in the same enterprise. One is a scientist anxious to find out something new about the natural world; the other may be a magician or conjurer anxious to make a living out of highly developed skills of deception. The difficulty of ensuring a shared commitment is one reason why paranormal phenomena have had so little influence upon science.

Thus scientists have to rely upon the written reports of other members of the society of scientists. This explains why a scientist caught lying in print is treated much more severely than, say, a journalist. In the 1970s, the scientific reputation of the eminent psychologist, Sir Cyril Burt, plummeted following the publication of evidence that he had fabricated results on the intelligence testing of separately reared identical twins. He invented results which supported his belief that intelligence is largely hereditary. If caught in such acts of fraud, the scientist will fall from grace very rapidly indeed.



FIGURE 2 A spoon-bender.

1.2 THE SCIENTIFIC METHOD

How is scientific knowledge obtained? What is distinctive about the scientific method? Few scientists give much thought to these questions, but among philosophers they are very controversial. What we shall do here is to put forward a simple version of one common theory of the scientific method (a theory associated with the name of Sir Karl Popper), and then express a few reservations about it.

Everyday experience teaches us a good deal about the world around us. In particular, certain patterns and regularities soon become apparent. For example, consider an observer who, while he was looking out of his study

window today, noticed that the Sun rose on his left and set on his right. The observer can make a formal record of this:

1 'Today, 11 November 1986, when I faced the oak tree opposite my study window, the Sun rose on my left, and set on my right.'

Suppose also that the observer recalls that the same thing happened yesterday:

2 'Yesterday, 10 November 1986, when I faced the oak tree opposite my study window, the Sun rose on my left, and set on my right.'

Because of this curious coincidence, the observer may now hazard a third statement:

3 'If I stand facing the oak tree opposite my study window, the Sun always rises on my left, and sets on my right.'

Statements 1 and 2 are *singular* statements which describe a state of affairs at one particular place and time. Statement 3, although prompted by statements 1 and 2, is clearly different in kind. In particular, it is much more *general*: it claims to tell us what has always happened in the past, and what will always happen in the future.

The process of generating general statements from singular statements is called *induction*. It is an essential part of science, yet it is not what distinguishes science from other fields of study. Induction is an exercise of the *imagination*: it leads from what *is*, to what *might be*. A stage in which the imagination works on what is already known is something that science shares with politics, religion and the arts. What is distinctive about science is the *form* of its general statements: in particular, they can be *tested* by observations and experiments. This makes such statements potentially falsifiable. According to the **falsifiability criterion**, a general statement can be scientific if and only if one can conceive of an observation or experimental result that can logically prove it wrong.

Consider statement 3 again. Its virtue lies in its power of prediction. If it is true, then the observer can derive from it a new singular statement:

4 'Tomorrow, 12 November 1986, if I face the oak tree opposite my study window, the Sun will rise on my left and set on my right.'

This derivation of a singular statement from a general statement is a process known as *deduction*. In its direction, it is the opposite of induction: from the general to the singular rather than vice versa. But the difference goes deeper than this. Deduction is a *logical* process: if statement 3 is true, then statement 4 *must also be true*. By contrast, induction is an imaginative process, not a logical one. When a general statement is created from a collection of singular statements, as with statement 3, we cannot be sure that it is true: it may well be false, and only time and experience will tell.

This brings us back to the point that statement 3 is potentially falsifiable. From it, the singular statement 4 has been deduced, and this can be tested by experiment. Suppose that tomorrow the observer witnesses sunrise and sunset from his study window. If the Sun rises to the left and sets to the right, then statement 4 is true, and statement 3 has survived a test. But if, for instance, the Sun rises to the right and sets to the left, then it is not just statement 4 that is false: statement 3 is false as well, and must be rejected.

Notice the asymmetry of these two possible outcomes. If statement 4 turns out to be false, statement 3 is false as well. But if statement 4 turns out to be true, it does not follow that statement 3 is also true: it remains possible that the Sun will rise and set in unexpected places the day after tomorrow. We can never say that the general statements of science are true; when they survive experimental tests, we say rather that they have been supported or *corroborated* by new evidence. If statement 4 turns out to be true, we retain statement 3 simply because it has not yet been falsified. And if retained, then like other general statements of science it could be useful. For example,

MODEL

suppose the observer works all day, and therefore does his washing and hangs it out to dry at night. He can now change the position of his washing line so that it catches the morning Sun.

One important characteristic of statements judged to be non-scientific by the falsifiability criterion, is that they often contain let-outs which prevent falsification. For example, consider the statement:

The Sun moves across the sky because it is pushed by an angel whose presence cannot be detected.

Here the let-out lies in the words 'cannot be detected': falsification is impossible, by definition.

Our trivial preoccupation with the view from the observer's window may seem far removed from real science. Recall, however, Einstein's words quoted at the beginning of this Unit: 'The whole of science is nothing more than a refinement of everyday thinking.' Many important scientific discoveries have followed the kind of sequence we have just described. Contact with a set of observations triggers the formulation of a general statement. A general statement in science may be called a law, a hypothesis or a theory, a distinction that we shall not elaborate here. What is important about the general statements is that new, singular statements or predictions can be drawn out of them by deduction. These predictions can then be tested, for example by experiments that have not previously been tried. If the predictions turn out to be wrong, the theory can be regarded as falsified, and then rejected. But if they are correct, the new theory may arouse the interest of other scientists and gain their provisional acceptance. Indeed, a truly great theory will, by its boldness and imagination, excite new thoughts, and also give rise to tests and experiments that would otherwise not have been done. In such a case, the theory can be described as fertile: it creates a large, new and complex research programme of its own. Later in the Course, you will see how the theory of continental drift did this in the Earth sciences (Units 7–8), and how Mendelée's idea about the behaviour of the chemical elements, the Periodic Law, achieved it in chemistry (Units 13–14).

What has been described above certainly captures important aspects of science, notably the inductive–deductive sequence, and the testing of the deduced consequences of laws and theories by experiment. However, its emphasis on falsification has aroused a good deal of argument. First, there is the question of whether all scientific theories are falsifiable. This has been raised in connection with the theory of evolution which you will meet in Unit 19. The theory can certainly be tested and corroborating evidence for it can be found, but it is hard to imagine experiments that could falsify it. Second, a single falsifying experiment rarely has the cutting edge needed to destroy an important theory, especially if the theory is well established and there is nothing to put in its place. Falsification takes time, mainly because scientists are reluctant to abandon the theories through which they have learnt their trade and made their living. And finally this view of science stresses a rather particular role of experiments: they are attempts to falsify or, failing that, to corroborate laws and theories. But modern experiments often call for sophisticated equipment and great technical skills. The sheer joy of exercising such skills in unknown scientific territory will often carry a scientist through an experimental programme without a thought of the possible falsification of a theory. Indeed, we hope that you will catch a flavour of this in Unit 2 when you measure the distance between the Earth and the Moon.

Yet whatever one's reservations, the vision of science discussed in this Section is an exhilarating one: experience combines with imagination to produce bold and exciting theories. But then, admitting the possibility of error, science tries to destroy the fruits of its own imagination with experiments. Either error is exposed by falsification, or the theory survives — but survives only provisionally. For science can never give us *final* certainty or truth; it advances over the wreckage of its own rejected theories. Is this really science, or is it a prescription for what science ought to be? When you have finished this Course, you will be better placed to decide.

1.2.1 MODELLING: A PART OF THE LANGUAGE OF SCIENCE

When you describe things to other people, you often use metaphors or analogies. Thus, 'my brother is a snake' or 'the Chairman of the S102 Course Team is a saint'. Scientific theories also contain metaphors, but they are normally more elaborate than those of ordinary speech. Scientists call them *models*. The term can be defined as follows:

A **model** is an artificial construction invented to represent or to simulate the properties, the behaviour or the relationship between individual parts of the real entity being studied.

This definition may appear somewhat abstract, so here are some concrete examples:

Example 1 The human heart is a complicated organ, but its main role may be thought of as that of a pump. Thus a pump in a central heating system is a model of the heart.

Example 2 Long before space travel, certain observations led people to conclude that the Earth was round. Thus a sphere became a model for the Earth.

The next example comes from Unit 20. Read it carefully once, and do not worry if you do not fully understand it. You should still be able to follow the subsequent comments.

Example 3 The controlled interbreeding of tall and short pea plants yields only tall plants in the first generation of offspring, but an approximately three-to-one ratio of tall to short plants in the second. This can be understood by using a model of inheritance. Each mating plant contributes something represented by one of a pair of letters, either *T* or *t*, to form a new pair, which can be either *TT*, *Tt* or *tt*. The combinations *TT* and *Tt* yield tall plants; the combination *tt* yields short plants. The original tall plants are each represented by the pair *TT*, and the original short plants by the pair *tt*. In each generation thereafter, the relative proportions of the possible combinations of letters then account for the ratio of tall to short plants.

Notice first that when we use the term model, we are not speaking of plastic miniatures of ships or aeroplanes. In none of examples 1–3 does the word mean a scaled-down replica of a real thing. What we have instead is a situation in which scientists single out for attention some narrow aspect or particular property of a more complicated system. To help their thinking, they construct a model. The model represents the system freed of the additional complications that the scientist has chosen to ignore; it has been deliberately 'tooled' to do the particular job in hand. Thus in both examples 1 and 2 the complicated internal structures of the heart and the Earth do not feature in the model, and in example 2 the fact that the Earth is not exactly spherical is ignored. The model described in example 3 is even more striking in that it reduces the variations in size of a number of pea plants to various combinations of two letters representing the particular character under investigation. A shuffling of these pairs of letters, to form new pairs, enables us to predict the relative proportions of tall and short plants in a series of generations.

Example 3 also provides an instance of a particularly important type of modelling: *mathematical* modelling. In this particular case, the mechanism of inheritance is regarded as a mathematical process whose consequences can be calculated by the well-established laws of chance and probability.

In these models, there are signs of the intellectual ruthlessness of scientists. The wholeness of things is ignored or brushed aside in the impatient search for precise explanations of some particularity. Some great artists have found this aspect of science repulsive. One catches something of this in William Blake's portrayal of Isaac Newton (Figure 3) and in Jonathan Swift's account of the Laputians in *Gulliver's Travels*. The Laputians are

STAR

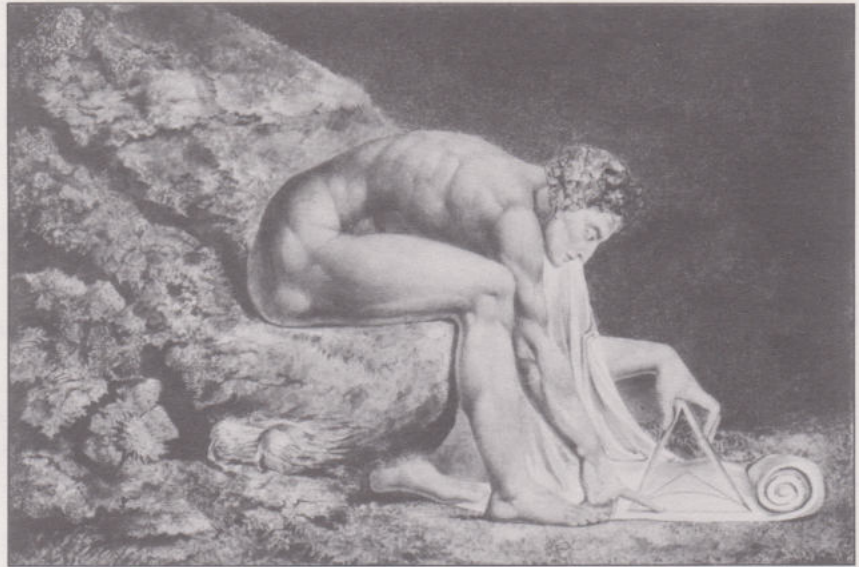


FIGURE 3 'Newton', by William Blake (1757–1827), the English painter, poet, engraver and mystic.

obsessed with mathematical problems and astronomy to the exclusion of other human and practical concerns. Gulliver's description of them symbolizes their two obsessions:

Their Heads were all reclined either to the Right, or the Left; one of their Eyes turned inward, and the other directly up to the Zenith.

Nor are their actions any more reassuring than their appearance. The typical Laputian:

is always so wrapped up in Cogitation, that he is in manifest Danger of falling down every Precipice, and bouncing his Head against every Post.

But do not be intimidated by this propaganda. Even if there is something in it, the study of science offers considerable consolation! You can now start to find out just how much.

SUMMARY OF SECTION I

- 1 Science is a social activity. It influences the structure of society, and society's demands influence the structure of science.
- 2 If scientists could not depend upon the truthfulness of other scientists' reports, rapid progress in science would become impossible.
- 3 According to one school of philosophy, science involves the creation of general statements or theories from observations and experience. This is an imaginative process. The general statements of science are falsifiable: they can, in principle, subsequently be refuted by testing their deduced consequences through experiments or further experience.
- 4 Models are an important part of the language of scientific theories. They are intellectual constructions, created by removing from the original all factors that appear to be of no relevance to the immediate scientific problem.

The following Self-Assessment Question, like all SAQs, may be attempted when you come to it in the text, and/or when you have completed the Unit.

SAQ 1 Assuming that scientific statements are those that conform to the falsifiability criterion of Section 1.2, try to classify the following as either scientific or not scientific.

- (a) All ravens are black.
- (b) If two bodies at different temperatures are placed in contact with one another and are isolated from their surroundings, the colder body never warms up.
- (c) Somewhere in the Universe, there exist, or have existed, extra-terrestrial life forms.
- (d) At the poles of the planet Mars, the planetary surface is always crawling with bug-eyed monsters.
- (e) One day, capitalism will everywhere be overthrown.
- (f) There is a ceremony that, if it is correctly performed, conjures up the Devil.

(Answers to SAQs are given at the back of the Unit, starting on p. 48.)

2 WHAT SHAPE IS THE EARTH?

In the rest of this Unit, you will be asked to consider questions concerning the Earth and its relationship to the Sun and the Moon. You probably already know quite a lot about this relationship from general knowledge; even if you do, bear with us for a moment.

How did you come to know that the Earth is round and that it spins about its axis and orbits around the Sun? More likely than not, you have just been led to believe it, because your parents and your teachers told you it was so from your early days. But can you *justify* why you believe it? Your eyes will tell you that the surface of the Earth is flat or undulating, depending on where you are, but certainly not that it is spherical. And you cannot possibly have any direct evidence from your senses about the *motion* of the Earth — when you keep still, the Earth seems to keep still as well. What you have accepted is a *model*, worked out by previous generations of scientists and gradually adopted into the pool of human knowledge.

It is a worthwhile exercise to try to forget all this knowledge for a moment and to retrace its derivation from everyday experience. The purpose of the remainder of this Unit is to guide you through this derivation, and to illustrate from this example how different aspects of scientific reasoning work in practice and how theoretical models are constructed, modified or rejected.

2.1 THE PANCAKE MODEL

Imagine for a moment that you are a member of a tribe living in the very distant past, in territory that consists of a large and relatively flat area. The area comprises meadows, lakes and woods, and is surrounded by impenetrable forests. Your tribal community supports itself entirely by hunting, fishing and primitive farming.

What sort of a picture could your tribe have about the place where they live? Surely they would be aware of the Sun, and of the fact that it provides warmth and also light that makes wild beasts visible for hunting (or avoiding). They might even notice that the heat and the light from the Sun help plants to grow (if only because they do not grow well in places shielded from it). On the other hand, they will also observe the Moon and the **stars**, which have no obvious relevance to everyday life. (You can think of a star as one of the vast number of incandescent celestial objects that can be seen in the night sky; this is certainly not a rigorous definition, but is adequate for the purposes of this Unit.) Even less understandable are some other natural phenomena such as wind, rain, snow, thunderstorms and earthquakes. They do not exhibit any obvious regularities and their effects on the well-being of the tribe are unpredictable, sometimes good, sometimes bad.

It is reasonable to speculate that an intelligent member of the tribe could formulate the following model of the world: the place where the tribe lives (the Earth) is like a flat pancake, and it does not move (earthquakes excepted); and the Sun is some sort of a glowing disc or fireball that moves repeatedly over the pancake. All other detail — such as what happens to the fireball when it disappears, how it gets over to the other side of the pancake, whether it is indeed the same fireball all the time or a new one every day — would be quite beyond this person's grasp.

Yet, in spite of its crudity, this very primitive pancake model already has an element of scientific approach in it. It is not just a direct, raw experience, it is an artificial mental image of something that cannot be directly perceived as a whole.

How would this model of the Earth be modified by another tribe that lived by the seashore or on an island, instead of being land-locked?

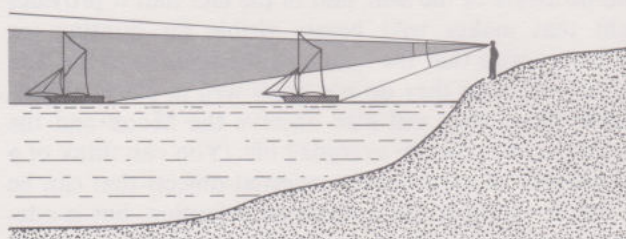
Well, their range of direct observations would be wider because they would observe the surface of the water extending as far as they could see, and would probably notice regular tides and possibly even the connection between the tides and the Moon. They would still regard the Earth as a pancake or a disc, but it would be either surrounded by water or floating on water like a huge boat. They might still regard the Earth as being 'at rest' (which is jargon for 'stationary'), because there is no sensation of its motion, not even of its floating on the water. The Sun would be moving around the Earth–water disc, or alternatively emerging from the waters and descending into them. The stars in the sky would be no more than some very distant and unreachable stage-setting; but the Moon could possibly be recognized as some object or mysterious being that has some influence on the tides, and that moves across the sky in much the same way as the Sun.

As long as direct observational experience is limited to a small part of the Earth's surface, the pancake model is the most sensible one, indeed perhaps the only reasonable one. There is nothing to suggest otherwise.

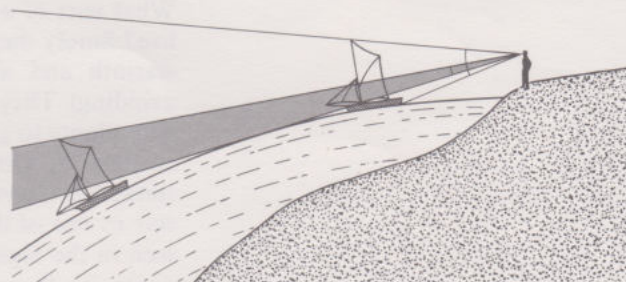
2.2 THE SPHERICAL MODEL

The flat-disc or pancake model of the Earth had to be abandoned only when people were able to collect and compare observations from much larger areas of the Earth's surface. These observations provided two kinds of evidence to suggest that the surface of the ocean is curved, not flat.

First, a large departing ship appears to be sinking into the waters on the horizon (Figure 4b), and an arriving ship to be emerging from them. Yet, sailors know that their ships remain on the surface all the time, and they in turn will testify that they saw the harbour and the shore sinking or emerging.



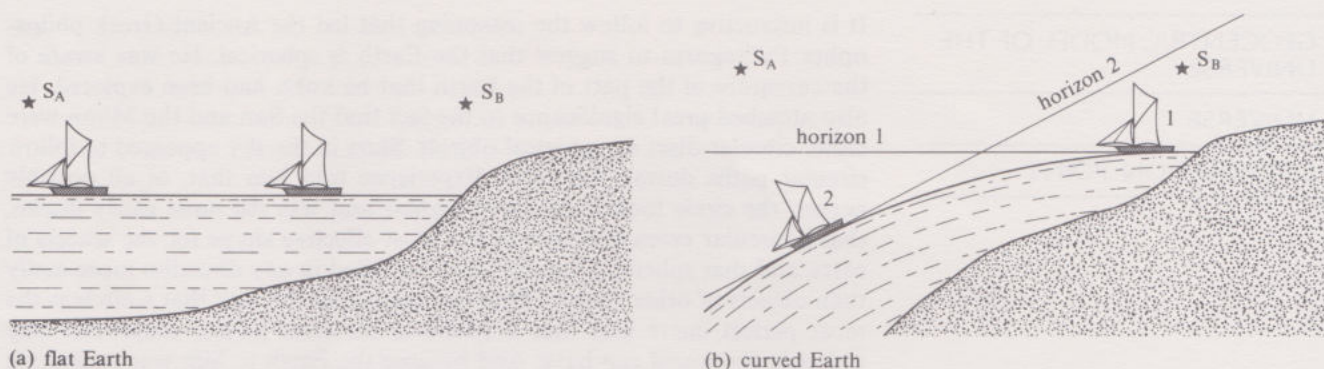
(a) flat Earth



(b) curved Earth

FIGURE 4 Visual evidence that the Earth is not flat. (a) If the Earth were flat, a departing ship would be seen to be diminishing, but always complete.

(b) A departing ship actually appears to be sinking as it disappears below the observer's horizon.



(a) flat Earth

(b) curved Earth

FIGURE 5 We know from observation of the stars that the Earth is not flat. (a) If the Earth were flat, both stars S_A and S_B would be seen from the ship, no matter how far it travelled.

(b) When the ship moves from position 1 to position 2, star S_A moves higher above the horizon and star S_B disappears.

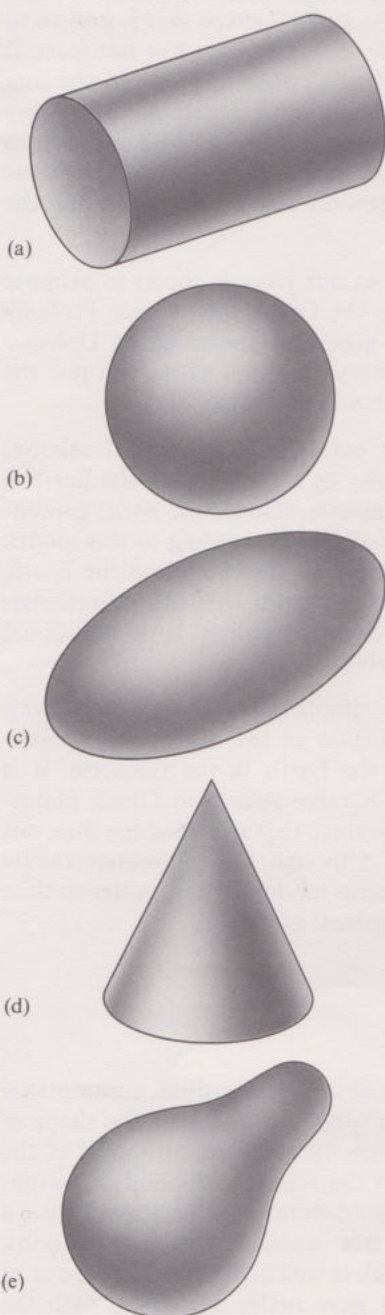


FIGURE 6 Five kinds of curved surface: (a) cylindrical; (b) spherical; (c) ellipsoidal; (d) conical; (e) pear-shaped.

The only possible explanation of this observation is that the surface of the water is not flat. And if the ocean surface is curved, it could be argued plausibly that the surface of the Earth *as a whole* is curved. (By the way, did you notice that this explanation involves the hidden assumption that everybody involved in these observations sees 'straight' or, in other words, that light travels in a straight line? This is a reasonable assumption in this case, but it is certainly not absolutely true!)

Second, the positions of the stars in the sky start to change as a ship travels south or north. The stars on one side of the horizon appear to the voyagers to be attaining higher and higher altitudes, and the stars on the other side appear to be moving lower down or even disappearing altogether. On the return journey, these changes are gradually reversed until all is the same again on return to the home port. It is obvious that these changes are not *real* changes in the appearance of the sky, because those who do not travel do not observe them. The changing pattern in the motion of the stars must therefore be due to the *changing position of the observer* in the ship. If the Earth and the ocean surface were essentially flat, this would be impossible. Provided that the distance to the stars is much larger than the distance travelled on Earth, then all stars would be seen in the same positions from all places on the land or the sea. Once again, the only possible explanation of the observed changes lies in accepting that the surface of the ocean is not flat, but curved (Figure 5).

Now try the following In-Text Question (ITQ). Remember that you should try to do the ITQs as soon as you reach them in the text, and then check your answers at the back of the Unit (in Unit 1, the ITQ answers start on p. 46). ITQs are an integral part of the teaching, so don't put off doing them till later!

ITQ 1 (a) On the basis of a single observation, of either of the kinds illustrated in Figures 4 and 5, one can conclude only that the Earth's surface is curved in *one* direction, namely along the direction in which the ship is moving. Can you tell, on this evidence alone, whether the surface is cylindrical, spherical, ellipsoidal, conical, pear-shaped or of any other curved shape (see Figure 6)?

(b) If not, what additional evidence would you need in order to show that the surface is spherical?

In doing ITQ 1, you have seen that although direct visual observation provides evidence that the surface of the ocean is not flat, it is not so easy to see why it should be spherical. True, it is possible in principle to repeat the observations and measurements from different places and in different directions, as we suggested in the answer to ITQ 1. However, all anyone could deduce from such measurements would be that it is *not impossible* that the Earth is spherical or, at the most, that it is *likely* to be spherical. But such a statement would be highly unreliable, particularly considering the state of technology at the time when a spherical model of the Earth was first suggested (about 500 BC, on present evidence).

GEOCENTRIC MODEL OF THE
UNIVERSE

UNIVERSE

CULMINATION POINT

It is instructive to follow the reasoning that led the Ancient Greek philosopher Pythagoras to suggest that the Earth is spherical. He was aware of the curvature of the part of the Earth that he knew had been explored. He also attached great significance to the fact that the Sun and the Moon were either circular discs or spherical objects. Stars in the sky appeared to follow circular paths during the night. Experience told him that, of all possible curves, the circle looked the most regular and was the most easily drawn, that a circular cross-section was the most effective shape for the wheels of carts, and that spherical objects could be rolled in any direction more easily than objects of other shapes. Thus he formulated the idea that a circle is the most perfect curve and that *a sphere is the most perfect shape* that any object in the world can have. And because the Earth to him was something of prime importance and perfection, at least as important and perfect as the Sun or the Moon, it seemed only natural to believe that it *must* be spherical.

This model of a spherical Earth represents a great advance of scientific thinking over the pancake model. First, it takes into account the observation that the surface of the ocean (and therefore probably of the whole Earth) is not flat. Second, it attributes to the Earth a shape that is known to be the shape of other important and 'perfect' things. Last but not least, it offers a very simple solution to the problem of what happens to the Sun after it has set. There is no need to worry any more about the possibility that it disappears into the ocean and is reborn again in some mysterious way the next morning. For, if the Earth is a sphere, then it somehow seems much more reasonable to argue that the Sun (as well as the Moon and the stars) travels in a circle around the Earth.

Although Pythagoras was the first (as far as our records show) to propose that the Earth has a spherical shape, it is the Greek astronomer Ptolemy who is now associated with the so-called **geocentric model of the Universe** (note that the **Universe** is the totality of everything that exists, not just the comparatively tiny region around the Earth and the Sun).

In about AD 150, Ptolemy produced an extensive catalogue of celestial objects and explained their motion in the sky by assuming that the Earth is a stationary sphere at the centre of the Universe. (Hence the name geocentric, where the prefix 'geo' is the Greek for Earth.) According to this model, the Sun, the Moon, the stars and the planets all travel around the Earth, either in simple circles, or in more complicated paths that can nevertheless be explained by combining one main circular motion with additional motions in much smaller circles around the main path.

The geocentric model, so attractive in its simplicity, also conformed with the Christian teaching concerning the creation of the world and human-kind, and concerning the special role of the Earth in the Universe. It is interesting that there was a different yet parallel stream in Greek philosophy (associated with Philolaus and Aristarchus) that regarded the Sun, not the Earth, as the centre of the Universe. Although this alternative model had at least as much merit as the geocentric model on the evidence then available, it was widely rejected on philosophical grounds.

SUMMARY OF SECTION 2

In this Section you have read about some of the observations, assumptions and reasoning that have led us to adopt a spherical model for the shape of the Earth. Also, you have met the geocentric (Earth-centred) model of the Universe. More important, you have seen the scientific method in action: observations gave rise to ideas, which could eventually be turned into a pancake model of the Earth's shape. But when further observations, coupled with reasoning, falsified this model, it was abandoned in favour of another model (the spherical model) that gave better agreement with the observations. Notice how well this sequence fits in with the account of the scientific method and of modelling given in Section 1.

Note that the spherical model was adopted long before there was any direct visual evidence of the spherical shape of the Earth. Yet scientists had faith in it because it was consistent with other observations that it alone could satisfactorily explain. Science is not just about what we can see; it also uses reasoning to ensure that all the relevant observations and evidence are consistent with one another and with the theory under examination.

3 THE EARTH AND THE UNIVERSE: EVERYDAY EXPERIENCE AND OBSERVATIONS

In the previous Section, you were mainly concerned with the Earth and the ways in which ideas about its shape were deduced from everyday observations. The models suggested depended on the life-style and natural environment of those making the observations. The relationship between the Earth and other celestial bodies, in particular the Sun and the Moon, were mentioned only briefly.

In theory, the simplest and most reliable answer to the question of how the Earth relates to the Sun and the Moon would be found by travelling sufficiently far away from all three of them and having a look 'from the outside', as it were. Alas, this is not yet fully possible for human beings. Nevertheless, we should still be able to develop an understanding of this relationship, even within the limitations of our Earth-bound observations. What we must do is to analyse these observations carefully, and use the information that we glean to build a satisfactory picture of the relative positions and motions of all three bodies.

In this Section, we shall summarize the available evidence. Then, in the next Section, we shall develop a simple model based upon this evidence.

3.1 DAYS AND NIGHTS

The regular sequence of days and nights is one of the most common experiences shared by all people, and indeed by all living creatures on the Earth. It is taken so much for granted that it represents an ideal of certainty, permanence and regularity.

Yet a closer look soon reveals that this sequence does not have a perfectly rigid pattern. To begin with, it is *not the same for the whole Earth*. The Sun rises earlier for an observer in Tokyo than for one in Paris. Nowadays this can be easily established, and the difference in time accurately measured, thanks to long-distance communications by telephone or radio. Moreover, even an observer who stays put in one place will experience *variations in the relative length of daylight and darkness*. These variations are related to the position of the Sun in the sky. Approximately half-way through the daylight period (noon), the Sun reaches its highest point above the horizon, known as the **culmination point**. This culmination point does not remain at the same place all the time, and it is common knowledge that days are long when the Sun culminates high above the horizon, and short when the culmination point is low. The relationship between the height of culmination and the length of daylight connects the day-night cycle closely with the cycle of seasons.

Before we delve further into this connection, let us emphasize one crucial observation about the day-night cycle. Although there are local as well as seasonal variations in the relative length of days and nights, the time interval *between two consecutive culminations* of the Sun is constant. It is the

SOLAR DAY

LUNAR PHASES

same for all observers anywhere on the Earth and is the same throughout the year (except for the extreme polar areas, where the Sun does not appear above the horizon for a long time during polar winters). For this reason, the interval between two consecutive culminations of the Sun became one of the first natural units for measuring time, and is known as a **solar day**.

3.2 THE FOUR SEASONS

When the relative durations of daylight and darkness within each solar day are systematically measured and recorded over several years, a clear pattern emerges that repeats itself regularly. This pattern is reflected in seasonal climatic changes, and there is an obvious relationship between the length of the day, the height of the culmination of the Sun, and the amount of light and heat received from the Sun at the place where the observations are being made. Table 1 summarizes these observations, starting from the summer.

TABLE 1 The seasonal cycle in the Northern Hemisphere

Relative lengths of daylight and darkness	Culmination point of the Sun	Name of day (date in Northern Hemisphere)	Climatic observation	Name of season that begins on this day
longest day and shortest night	highest	summer solstice (21 June)	hot	summer
day and night of equal length	average	autumnal equinox (23 September)	mild	autumn
shortest day and longest night	lowest	winter solstice (21 December)	cold	winter
day and night of equal length	average	vernal equinox (21 March)	mild	spring

As you are well aware, different parts of the Earth do not have the same season at the same time. When Britain enjoys (!) its summer, Australia has to endure its winter. In fact, the whole pattern is *reversed* for the parts of the Earth to the north and south of the Equator (the Northern and Southern Hemispheres, respectively). Furthermore, the *intensity* of seasonal changes *varies with location*. Around the Equator, seasonal changes are hardly noticeable, but in the arctic regions they are so great that even the usual day–night cycle is temporarily obliterated. There is a time (which amounts to several months at the poles) during which an arctic observer always sees the Sun moving above the horizon and never setting below it (polar day in the arctic summer) and a similar period during the arctic winter when the Sun never emerges above the horizon (polar night).

However, in spite of all these local variations, there is one common feature. For any place on Earth, the time interval between two identical observations is the same (for example, between two consecutive summer solstices, see Table 1). Thus there is some underlying regularity reflected in the *constant length of one complete seasonal cycle*, whatever its local details.

Incidentally, in order to avoid any confusion or misunderstanding that might arise from the fact that many observations are different at different parts of the Earth's surface, let us agree, from now on, that any observations described or explained will be those that can be made in Britain or in places of similar latitude within the Northern Hemisphere, unless specifically stated otherwise.

3.3 THE SUN AND THE MOON

The Sun and the Moon appear to be the two largest natural objects visible in the sky, and are the *only* two objects that appear to the unaided eye as large circular discs. All other celestial bodies visible at night appear just as small points of differing brightness.

The first interesting observation to make is that the Moon, when seen full, appears to be of about the same size as the Sun. But you know from everyday experience that the *apparent size* of an object does not tell you anything about its *real size*, unless you also know the *distance* of that object from you. A matchstick held at arm's length appears longer than the mast of a television transmitter a few miles away! At this stage, we are not concerned about the real sizes of the Sun and the Moon, or about measuring the distances to them. All we need is the observation that *the apparent sizes of the Sun and the (full) Moon each remain constant in time*.* This means that whatever their distances from the Earth, these distances cannot be changing to any great extent.

The Sun is the source of nearly all the light and heat that reaches the surface of the Earth. The Moon, by contrast, is much less bright and provides no heat. It can be seen more clearly during the night, although it is frequently above the horizon during the day. The most striking feature of its appearance is that, unlike the Sun, the Moon is not always seen as a full circular disc. It undergoes a cycle consisting of **lunar phases**, as shown in Figure 7. These changes of shape correspond to the changes in the time of day or night during which the Moon can be seen above the horizon (provided that it is not obscured either by clouds or by bright sunshine). The whole cycle from one new Moon to the next is spread over approximately 28 day-night cycles.

LUNAR PHASE	TIME WHEN VISIBLE
 new Moon	during the day, near the sun
 waxing crescent	most of the day and early evening
 first quarter	afternoon and first half of the night
 waxing gibbous	evening and most of the night
 full Moon	all night
 waning gibbous	most of the night and early morning
 last quarter	second half of the night and morning
 waning crescent	before sunrise and most of the day
 new Moon	during the day, near the Sun

FIGURE 7 Phases of the Moon and its visibility above the horizon.

* This is certainly true within the accuracy of observations made by unaided eyes or with the help of small telescopes. The fact that the Sun sometimes *seems* bigger when it is very low above the horizon has nothing to do with its distance. In part, it is due to the bending of light in thick layers of dense atmosphere, but the impression is reinforced by psychological effects.

POLARIS
CONSTELLATION
PLANET
RETROGRADE LOOP
PERIODIC PROCESS
PERIOD
THOUGHT EXPERIMENT
EXPERIMENTAL DATA (p. 20)

Another interesting characteristic of the Moon is the appearance of the darker areas seen on its surface. The shape of these features (the 'Man in the Moon') does not change appreciably with time. More important, their relative positions on the face of the Moon also appear to be constant. They temporarily disappear as one part of the Moon progressively darkens, but they reappear in the same places when that part of the Moon brightens up again. The Moon appears always to show *the same face* to the Earth.

3.4 THE STARS AND THE PLANETS

During the night, the stars appear to be moving across the sky. Closer observation reveals that in the Northern Hemisphere there is one particular star, **Polaris**, that does not seem to be moving at all. For this reason, its position in the sky has been used through the ages as a reference point for navigation.

Although some of the stars appear to be moving faster than others, there is a fascinating degree of coordination in their motions. Each individual star travels in a *circle* with respect to Polaris. Furthermore, stars are grouped at all times in the same relative configurations, known as **constellations** (*stella* is the Latin for star); two well-known examples are The Plough and Orion. Constellations appear to be remarkably stable: by comparing the present appearance of the constellations with those of the past (as recorded by ancient astronomers), we can deduce that there have been only very small changes in the shapes of some constellations over thousands of years.

By contrast with this relatively steady and highly regular pattern of the stars, there are a few very bright star-like objects that appear to move across the sky without having a fixed relationship to any of the constellations. Since they appeared to be 'stars on the loose', so to speak, the Ancient Greeks named them **planets**, meaning 'wandering stars'.

The most unusual feature in the behaviour of the planets is the shape of their paths with respect to the constellations. If you were to plot the relative position of a planet as seen from Earth (such as the position of Mars or Jupiter with respect to a constellation), the path could look something like Figure 8, where each successive small circle represents the relative position of the planet at the same time on successive nights. This is nothing like a segment of a circle! These loops, during which a planet appears to be turning back for a while, are accordingly called **retrograde loops**. The absence of any obvious reason for such behaviour was a weakness of the geocentric model, and this weakness led eventually to the model's demise.



FIGURE 8 A retrograde loop in the path of a planet with respect to a chosen constellation, as seen from Earth. (Not drawn to scale.)

3.5 THE PERIODICITY OF EVENTS

In spite of their local variations, all the observations discussed earlier in this Section indicate that there is a basic underlying regularity and an intrinsic order in the Universe. Night always follows day, spring follows winter, the first quarter of the Moon follows the new Moon, and so on.

If you choose one particular event or situation, for argument's sake the full Moon, you will observe that after a sequence of changes this particular event or situation will be repeated. Moreover, the sequence of events between the two identical situations will also be repeated. A process in which an event is repeated at regular intervals is called a **periodic process**, and the time taken to complete the sequence *once* is called the **period** of the process.

In everyday life, there are many examples of periodic processes, for example the rotation of a turntable and the swinging of a clock's pendulum. Furthermore, as you will see not just in this Unit but in the rest of the Course, periodic processes are very important throughout science. So it is worth taking a little time now to derive a better feeling for the ideas involved in

the concept of periodicity. To this end, we should like you to consider an experiment. It will not involve any actual apparatus; instead, you will do it by visualizing the apparatus and by considering theoretically a situation that we shall describe. This is an example of a **thought experiment**.

Scientists are generally very fond of thought experiments, not least because they are very convenient (and cheap). However, the performing of a thought experiment certainly cannot always be regarded as an alternative to the performing of a real experiment — in the end, a theoretical idea stands or falls according to its success in accounting for the results of real experiments.

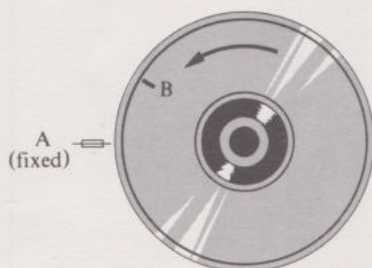


FIGURE 9 The rotation of a compact disc.

3.5.1 A THOUGHT EXPERIMENT: THE ROTATION OF A COMPACT DISC

Imagine a compact disc rotating in a player (Figure 9). Think of two reference points — one just *outside* the disc on the stationary base of the machine (point A in Figure 9), and the other *on* the rotating disc (point B). In ITQ 2, we ask you to consider this imaginary apparatus.

ITQ 2 Assume that the compact disc rotates at a constant rate of 5 revolutions per second.

- How long does it take for the disc to complete 10 revolutions?
- How long does it take for the disc to complete 1 revolution?
- What is the period of rotation of the disc?

3.5.2 INVESTIGATING THE PERIODS OF PENDULUMS

From ITQ 2, we hope you have begun to get a feel for periodic processes. Now, we should like you to extend your understanding by doing a *real* experiment! As with all experiments in the Course it is best to read through the instructions (as far as the end of the text in the box) *before* doing the experiment.

EXPERIMENT 1 INVESTIGATING THE PERIODS OF PENDULUMS

TIME

This experiment takes about 30 minutes

NON-KIT ITEMS

(to obtain yourself)

three lengths of thin string — at least 1.2 metres, 70 centimetres and 50 centimetres long, respectively

two small heavy objects of different weights, e.g. two bunches of keys, to which you can easily tie a string

watch that can measure time in seconds, or a stop-watch

Notebook (*Note: you will require this for every experiment in the Course, for recording your results.*)

KIT ITEMS

None required for this experiment.

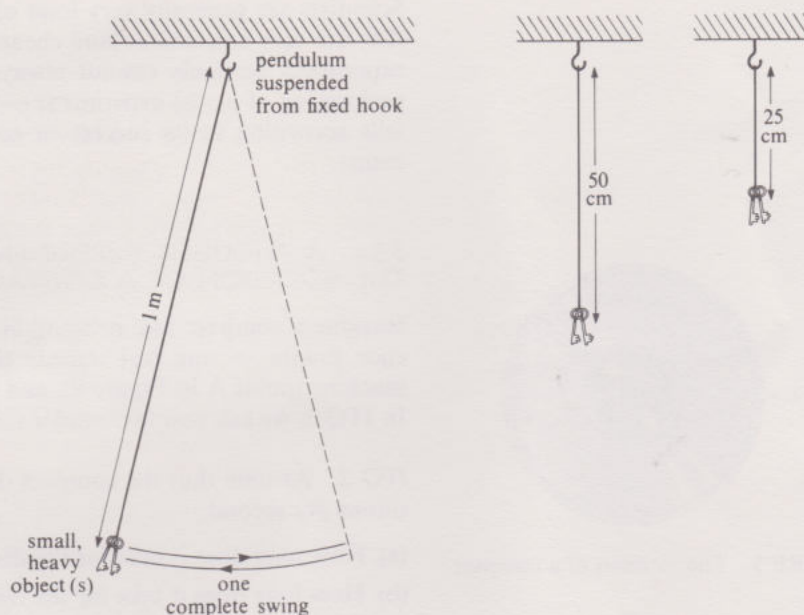


FIGURE 10 Apparatus for Experiment 1.

METHOD

Part 1

How does the period of swing vary, when you alter the length of a pendulum?

- 1 Refer to Figure 10. Take a piece of thin string, about 1.2 metres long, and tie the lighter of your small heavy objects to one end. (A weight at the end of a pendulum is usually called a bob.)
- 2 Tie the other end to a fixed point (such as a hook), taking care to ensure that the *total* length of the pendulum (from the bottom of the hook to the middle of the weight) is within a few millimetres of 1 metre. Make sure that the pendulum can swing freely. (If you really can't find any other way of supporting the pendulum, you can, as a last resort, simply hold the free end in your hand.)
- 3 Copy Table 2 (below) into your Notebook, ready to enter your **experimental data**, i.e. the measurements and observations you obtain when you do the experiment. (You will need the column headed 'Period (in seconds)' later.)

TABLE 2 Results of Experiment 1

Light or heavy bob	Length of pendulum	Time for 10 swings (in seconds)			Period (in seconds)
		1st reading	2nd reading	average: (1st + 2nd)/2	
light	1 m				
light	50 cm				
light	25 cm				
heavy	1 m				

4 Hold the watch with a second-hand so that you can see the pendulum and the watch at the same time. (If you have a watch with a stop-watch facility, use this for measuring the time elapsed — and you won't need to hold the stop-watch where you can see it.)

5 Start the pendulum swinging. Measure the time it takes the pendulum to execute 10 *complete* swings, and enter this in the top row of the '1st reading' column in your Table of results. Repeat this procedure, and enter the new result in the '2nd reading' column of the top row in your Table; your two results should, of course, be identical or similar. Calculate the *average* time it takes the pendulum to execute 10 complete swings (the average time is calculated by adding the two recorded times and then dividing the result by two). Record this time in the 'average' column of the top row in your Table.

6 Remove the bob of the pendulum (i.e. the object at the end) and put the string to one side (*you will need it for Part 2, and for Experiment 2*).

You are now going to repeat the experiment with two more pendulums (with lengths 50 and 25 centimetres).

7 Make another pendulum of total length 50 cm, using the same object and the 70 cm length of string. Measure the time this pendulum takes to make 10 complete swings. Record your result in the '1st reading' column of the second row in your Table. Repeat the procedure with the same pendulum, recording the result in the '2nd reading' column. Then calculate the average time as before, recording your result.

8 Use your third piece of string (and the same object) to make a pendulum of total length 25 cm. Follow the same procedure to obtain an average time for 10 complete swings and record all your results in the third row in your Table.

9 Calculate the periods for each of the three different lengths and complete the first three rows of the Table.

Part 2

If you increase the mass at the end of your 1 metre pendulum, what will be the effect on the period?

You are now going to do the experiment with a 1 metre pendulum again, but this time use a *heavier* object as a pendulum bob (e.g. add the second bunch of keys).

10 Take this heavier object, and the 1.2 metre length of string, and repeat procedures 1–6 of Part 1; but this time record your results in the final row of your Table. (Remember to keep the length of the pendulum as close to 1 metre as possible.)

(Again, keep your 1.2 metre length of string: you will need it later for Experiment 2.)

Note: In every experiment in the Course, when you reach the end of the boxed text this signifies that you have finished the practical part of the experiment and can put away the apparatus. It is time to analyse your results.

ITQ 3 How does the time taken to complete 10 swings change when you shorten the length of the pendulum?

ITQ 4 What effect does shortening the pendulum's length have on the period of the pendulum's swing?

ITQ 5 When you increased the mass of the bob on your 1 metre pendulum, was the effect on the period as you expected?

3.5.3 PERIODICITY IN NATURE

Let us now return to the main story. Note that the determination of the period of a periodic process *assumes* that it is possible to measure time. However, the scientific concept of time and the techniques of time measurement are themselves firmly based on the periodicity of some natural processes. Thus, one of the first units of time was called a solar day and was defined as the interval from one culmination of the Sun to the next. Similarly, one could define a lunar month as the time between two consecutive full-Moon phases, and a solar year as the time between two consecutive summer solstices. These are perfectly adequate units for everyday use. But when it comes to the need for high accuracy they are not so good. It is rather tricky to establish *exactly* when the Sun reaches its culmination point or exactly when there is a full Moon. Also, when two solar days at different times of the year are compared very carefully, they are found not to be identical — there are small, but measurable, differences. For more accurate timekeeping, scientists nowadays look to other processes whose periodicity is more reliable. We shall look into this in much more detail in the next Unit.

SUMMARY OF SECTION 3

- 1 The periodic cycle of days and nights is determined by the relative motion of the Sun and the Earth. The precise details of this cycle vary, depending on where the observations are made on the Earth's surface.
- 2 There are longer-term, seasonal changes in the relative lengths of daylight and darkness within one solar day. These seasonal changes are related to the culmination point of the Sun and also depend on the place of observation.
- 3 The Sun and Moon are of roughly the same apparent size. Their distances from the Earth (not yet discussed in this Unit) do not change considerably with time (otherwise their apparent sizes would be observed to change).
- 4 The Moon exhibits a periodic cycle of lunar phases and has some apparently stable structural features on its surface. It appears always to show the same face to the Earth.
- 5 In the Northern Hemisphere, the stars appear to move in circles around Polaris.
- 6 Against the background of constellations, the paths of the planets (as observed from Earth) follow retrograde loops.
- 7 Astronomical observations show periodicity, and this enables predictions to be made even without any understanding of the system of the Universe. Periodic processes serve as a means for measuring time.

The aim of this Section was to summarize the observational evidence that can be used for the construction of a model describing the relationship of the Earth to the Sun and the Moon. In addition, you should have gained some understanding of periodic processes and have had your first taste of interpreting the results of simple observations and experiments.

4 THE EARTH, THE SUN AND THE MOON: BUILDING A MODEL

You saw in the previous Section that the Earth, Sun and Moon cannot be stationary with respect to one another. There is undoubtedly motion: but what is moving and how?

In most everyday situations, when you move (or are moved) you have a sensation of motion. But if you sit tight on a piece of rock, or anything else firmly attached to the surface of the Earth, there is no sensation that the Earth as a whole is moving. It was, therefore, only natural for most of our ancestors to believe that the Earth is stationary and that everything else is moving around it.

But is it reasonable to rely on human senses for the detection of motion? How sensitive or reliable is our sensation of motion? Consider the following imaginary situations:

1 You are travelling in a train on a perfectly straight and level track. You have just woken up from a short nap, and the first thing you see through the window is another train, just like yours, passing by. Do you think that you would be able to distinguish instantly — and without reference to other observations such as the landscape, buildings etc. — between the following possibilities:

- (a) your train has stopped at a station, through which the other train is passing;
- (b) your train is moving past another train that has stopped at a station;
- (c) both trains are moving, in opposite directions;
- (d) both trains are moving in the same direction, but one of them is travelling very much more quickly?

2 You have entered the 'cage' of a lift on the thirtieth floor of a sixty-floor skyscraper. You have not checked the light signals, did not register the initial jerk as the lift started, and the lift is now moving at a steady speed. Can you be absolutely sure at any moment whether you are travelling up or down? When will you be sure and what would you feel?

Well, the answer to these questions is, in general, 'no' — the human senses cannot always distinguish between rest and motion. The only situations in which you have a very clear sensation of motion are those in which *the state of motion is changing*. Thus, the speeding-up of the lift as it starts to ascend makes you feel pressed against the floor, and the slowing-down before it reaches the upper floor makes you feel as though you are floating upwards. The feeling is caused by the relative motion of some internal organs (the stomach in particular) with respect to the more rigid frame of your body. The sensitivity is slightly greater for up and down changes than for sideways motions, but it is generally true that a *steady* motion, in the same direction and at the same speed, is undetectable. And it is worth stressing that this is not because of any particular inadequacy of the human senses. There is no experiment and no instrument that could detect the steady motion of any system *from within that system*. This is one of the most fundamental features of the world, verified by countless experiments.

But what about motion in a circle, such as on a rotating turntable or a roundabout? Well, the problem here is that this is not a steady motion. Even if the *speed* of rotation is constant, the *direction* of motion is continuously changing, and you can feel this motion when you sit on a rotating roundabout. But even here, human senses are not only fallible but also very adaptable. It is well known that after a sufficiently long exposure to some roughly constant influence — smell, noise, pressure, etc. — people can become so used to it that they actually become unaware of it. It is not very difficult to imagine that if someone spent most of their life in the seat of a smoothly and steadily rotating roundabout, without any reference to the

SPIN OF AN OBJECT

AXIS OF ROTATION OF AN OBJECT

AXIS OF SPIN OF AN OBJECT

ORBITAL CIRCULAR MOTION

world outside, they would not have any sensation of rotation. Although such motion is always detectable by suitably designed experiments, it is not necessarily always registered by human senses and the human brain.

Thus, when it comes to answering the question of how the Earth relates to the rest of the Universe, there is *no justification for assuming that the Earth itself is not moving* — it may be or it may not.

4.1 THE EARTH AND THE SUN

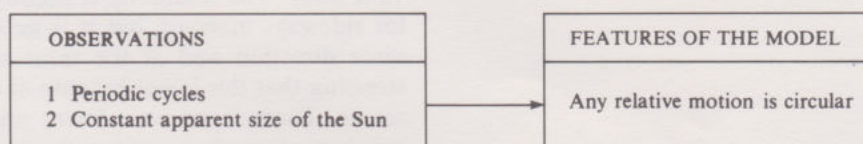
In order to understand the place of the Earth in the Universe, it is necessary first to understand its relationship to the Sun. The point has already been made in Section 3 that this relationship cannot be observed directly, but it can be represented by a suitable model.

It is reasonable, in view of the arguments advanced in Section 2, to start by representing the two bodies by two spheres. The sphere that represents the Sun can be assumed to radiate heat and light, and moreover we can assume that equal amounts of heat are radiated in all directions (and the same for light). Further developments of the model will consist of choosing appropriate relative motions of the two spheres that would *reproduce the observations* described in the previous Section. (Note that quantitative details of the model, such as the actual sizes and separation of the two bodies, will be deferred until Unit 2.)

What kinds of possible relative motion should you consider for the two spheres? If you recall the observation that both the day–night cycle and the cycle of the seasons are (in spite of all their local variations) essentially periodic processes, it is obvious that the relative motion of the two bodies must be *periodic*. That is, whichever of the two bodies is moving and however it moves, there can be only a limited sequence of possible different configurations of the two bodies and this sequence of configurations is regularly repeated. Furthermore, the observation that the apparent size of the Sun, as seen from the Earth, is always the same, can only mean that the two spheres must always be at the *same separation*.

- ☐ What type of motion satisfies these conditions of periodicity and constant distance of separation?
- It has to be motion in a circle. You might have thought that the motion of a pendulum bob also satisfies these conditions. But this can be ruled out because a pendulum bob periodically reverses its direction of motion, whereas the Sun always moves in the same direction.

Thus, by using two observations, you already have one necessary feature of any model for the Sun–Earth relationship:



4.1.1 TWO KINDS OF CIRCULAR MOTION

At this point, we must be careful to differentiate between two kinds of circular motion — spinning, and orbital circular motion.

When a body rotates about a (normally imaginary) fixed line that *passes through* the body, the body is said to be **spinning**, and the fixed line about which it is turning is called the **axis of rotation** (or sometimes the **axis of spin**). Examples of objects that execute spinning motion are the drilling bits in power tools, a child's spinning top, and pirouetting ice-skaters. Perhaps you can think of more.

On the other hand, when a body moves in a circular path about a point, the body is said to be executing **orbital circular motion**. Note, however, that it is conventional to use the term orbital motion also when the body follows a path that is not circular, but which nevertheless has a fixed, closed shape. In this way, the moving body will travel repeatedly, in the same way, during each complete revolution. The most common non-circular orbital path is the ellipse, an oval-shaped path which will be considered in more detail in Unit 2.

Common examples of orbital motion are greyhounds running around a closed race-track, seats on a merry-go-round, and a satellite orbiting the Earth.

Returning to our model of the two spheres representing the Sun and the Earth, there are many possible combinations of different motions. Either of the two bodies can orbit the other, and each of them may or may not spin. This variety of options can be reduced by taking into account the *appearance of the Sun*.

Does the Sun show any periodic changes of its shape or of its brightness from which one could conclude that it spins? No such changes have been noticed in everyday observations. Large telescopes reveal some very small spots of lower brightness on the Sun's surface (sunspots). The motion of these spots indicates that the Sun could be spinning with a period of about a month but, in spite of this, the overall amount of light and heat emitted from the Sun's surface remains the same in all directions and at all times (within a typical human lifespan, at least). It is therefore reasonable to ignore any spinning of the Sun, because it does not make any difference to Earth-bound observations.

This leaves only four different options for the motions of the Sun and the Earth, as shown in Figure 11.

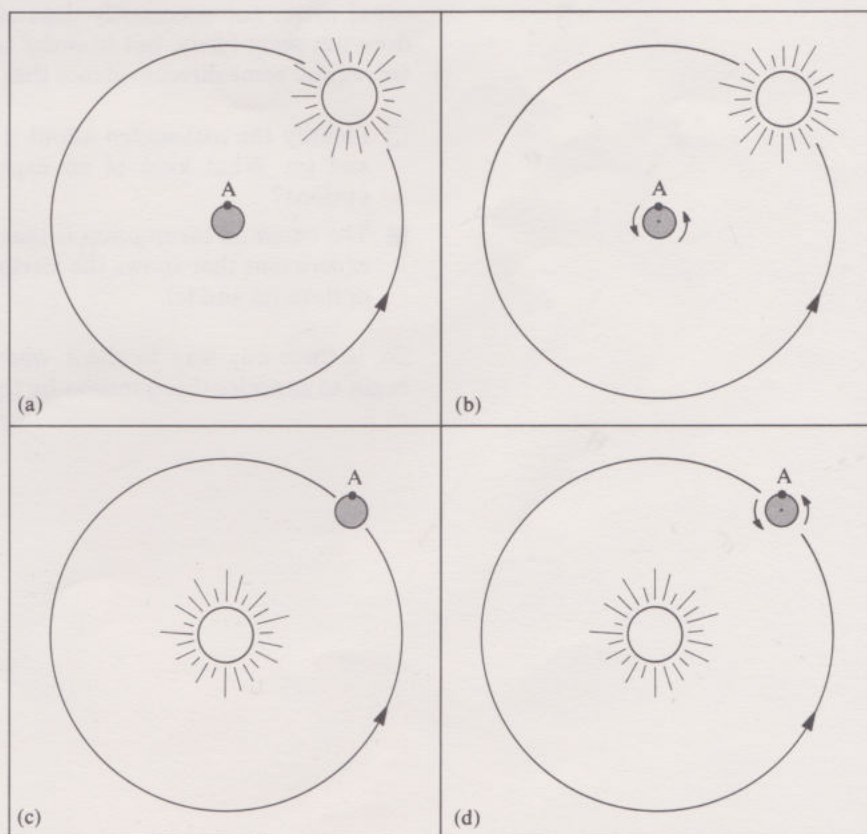


FIGURE 11 Possible options for the model of the Sun–Earth relationship. The dot labelled A represents an observer on Earth. The dot at the centre of the Earth, in (b) and (d), indicates the Earth's axis of rotation.

**FOUCAULT PENDULUM
EXPERIMENT**

The models in Figure 11 may be described as follows:

- (a) The Earth is stationary and does not spin; the Sun orbits around the Earth.
- (b) The Earth is stationary and spins; the Sun orbits around the Earth.
- (c) The Sun is stationary; the Earth orbits around the Sun and does not spin.
- (d) The Sun is stationary; the Earth orbits around the Sun and also spins.

(Note that stationary in this context does not mean motionless. It means a fixed position in space; spin is allowed.)

4.1.2 WHAT CAUSES THE DAY-NIGHT CYCLE?

Leaving aside everything else for the moment, option (a) could account for the day-night cycle, provided that the Sun could complete one full orbital cycle in one solar day. This would lead to very large, perhaps even impossibly large, speeds for the Sun, if its distance from the Earth is very large. Although this is a potential problem, it would not on its own justify the rejection of this option. A far more serious objection to (a) is that, having used the orbit of the Sun to explain the day-night cycle, there is no other motion left to account for the periodic seasonal cycle.

A very similar argument can be made against option (c). Once again, a day-night cycle could be accounted for by the Earth's completing one circle in one solar day, but there is no other motion left to explain any other periodic observations (the seasons).

Options (b) and (d) have the obvious advantage that two different motions are available and therefore more than one periodic observation can be explained.

But perhaps there might be some other explanation for the long-term seasonal cycle, not necessarily dependent on the spin or orbital motion? It does not seem likely, but in order to reject options (a) and (c) convincingly we require some direct evidence that they are wrong.

- ☐ Identify the *assumption* about the Earth that is common to options (a) and (c). What kind of an experiment would eliminate both of these options?
- ☒ The common assumption is that the Earth does not spin. Therefore, any experiment that shows the Earth does spin, conclusively eliminates both options (a) and (c).

So, is there any way to check whether the Earth spins? We'd like you to begin to consider this question by trying another pendulum experiment.

EXPERIMENT 2 INVESTIGATING THE DIRECTION OF THE SWING OF A PENDULUM

TIME

About 10 minutes

NON-KIT ITEMS

thin string, about 1.2 m long (you can use the longest piece of string from Experiment 1)

a small, heavy object, e.g. one of those from Experiment 1

METHOD

- 1 Using the string and the heavy object, make a pendulum of length 1 metre.
- 2 Find a fixed line on your floor, utilizing the pattern of your carpet, a row of tiles or something similar. Suspend the pendulum from your fingers and start it swinging along this fixed line. Keep your arm outstretched and imagine that your fingers holding the pendulum are at the centre of a circle.
- 3 Gradually move around in a complete circle, keeping the point of suspension of the pendulum fixed (Figure 12). Observe the motion of the pendulum with respect to the reference line.

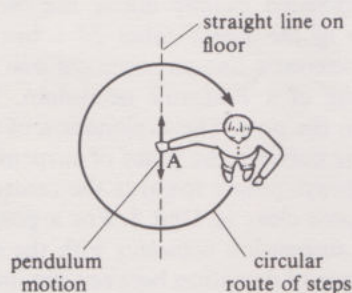


FIGURE 12 Experiment 2.

ITQ 6 As you moved round in a circle, did you observe any change (with respect to the fixed line on the floor) in the pendulum's direction of swing? What do you conclude?

Now imagine what would happen if, instead of walking in a circle around the swinging pendulum, you were standing on a rotating platform and held the end of the pendulum string above the centre of the platform. As far as the pendulum is concerned, the situation is exactly the same as before: the swinging object is freely suspended* from a rotating arm. So, in the rotating-platform case, the pendulum will always swing in the same plane, just as it did in your experiment.

- ☐ Does this suggest to you a possible experimental test that would show whether the Earth is spinning?
- ☒ All you would have to do would be to use a very heavy bob on a very long pendulum, suspended with a minimum of friction, so that it would go on swinging for several hours, once started. You would draw a reference line on the surface of the Earth, indicating the initial plane of swing, and then you would just sit and wait. If the Earth is not spinning, the pendulum would never deviate from this line. But what if the Earth, carrying the line, spins underneath the pendulum? After a sufficiently long time, there would be an obvious difference between the reference line and the plane of swing.

This is the basis of the **Foucault pendulum experiment**, which is demonstrated in the TV programme associated with this Unit, 'The planet Earth — a scientific model'. As you will see in the TV programme, this experiment

* By 'freely suspended' we mean that the motion of the bob is not restricted by any rigid coupling to the point of suspension. A long, thin string has very little restraining effect even if it is held fixed or tied up to a hook. However, if the pendulum had been made using a rigid rod instead of a piece of string, then some special suspension would have had to be designed in order to enable the rod to swing without friction in any direction.

enables us to reject options (a) and (c) because it shows that the Earth does indeed spin.

The Foucault pendulum not only allows us to reject options (a) and (c), it also helps us to clarify one important detail in options (b) and (d). In these options there are two periodic motions — the spin of the Earth, and the orbital motion of either the Sun (b) or the Earth (d); we need to connect these with two periodic observations — the day–night cycle, and the seasonal cycle. It may seem *intuitively* more reasonable to connect the spin of the Earth with the shorter of the two cycles, but it is the outcome of the Foucault pendulum experiment that provides a clear answer. Even without accurate measurements, it is obvious from the rate at which the plane of swing deviates from the reference line on the Earth's surface that the spin of the Earth accounts for the day–night cycle rather than for the seasonal cycle. In fact, a Foucault pendulum suspended exactly above the North Pole would show that *one turn of spin of the Earth takes 24 hours*. In Britain, it takes about 30 hours for the reference line to complete one full turn with reference to the plane of swing of a Foucault pendulum. The difference is due to Britain's distance from the pole. The explanation of this difference is based on the fact that the line between the point of suspension and the bob of a stationary pendulum always points towards the centre of the Earth — the reason for this will become clear in Unit 3. For a pendulum suspended over the pole, the line of suspension *coincides* with the axis of rotation of the Earth. This is why the rate of deviation between the initial reference line and the plane of swing of a Foucault pendulum at the pole measures *directly* the rate at which the Earth is turning about its axis of rotation. Above the Equator, on the other hand, the line of suspension of the pendulum is *perpendicular* to the Earth's axis of rotation and the Foucault pendulum would not show any deviation from the initial reference line. In Britain, the rate of deviation is slower than at the pole, because the line of suspension is at an angle of about 35 degrees (often written as 35°) to the Earth's axis of rotation.

Before taking the next step in our model-building exercise, let us sum up our progress so far.

OBSERVATIONS AND EXPERIMENTS		FEATURES OF THE MODEL
1 Periodic cycles (day–night, seasons) 2 Constant apparent size of the Sun	→	Circular motion required
3 Constant brightness and appearance of the Sun	→	Spin of the Sun non-existent or unimportant
4 Day–night cycle 5 Foucault pendulum	→	The Earth spins with a period of one solar day

4.1.3 WHAT COULD EXPLAIN THE SEASONAL CYCLE AND ITS LOCAL VARIATIONS?

In Section 4.1.2, the spin of the Earth was firmly linked with the day–night cycle. Therefore if option (b) or (d) is to explain the relative motion of the Earth and the Sun, it follows that the second periodic observation — the cycle of the seasons — could be connected only with the orbital motion. Either the Sun orbits around the Earth — option (b) — or the Earth orbits around the Sun — option (d) — and in either case the period of the orbital motion has to be exactly the same as that observed for a complete cycle of the four seasons — one solar year.

But there is a snag. Can you see what it is?

- ☐ What is the shape of the orbit (according to all the evidence so far)? Does this shape tie up with the sequence of seasonal changes?

- The orbit is circular (evidence for this is provided by the constant apparent size of the Sun). But if the two bodies are always at a constant separation, how can the amount of light and heat received from the Sun vary so much from one season to another?

Your everyday experience tells you that the nearer you stand to a fire, the more light and heat reaches you. Thus it seems reasonable to look critically at the conclusion reached earlier about the circular orbits. Perhaps there are some changes in the distance between the Sun and Earth after all? Perhaps it is just possible that these changes are large enough to explain the variations in the amount of light and heat that we receive on Earth at different times, and yet small enough not to make a noticeable change in the apparent size of the Sun.

Figure 13 illustrates two possible modifications that could be introduced into the relative motion of the two bodies. Note that in both cases the axis of rotation of the Earth is assumed to be perpendicular to the plane of the orbit (which is in the plane of the paper).

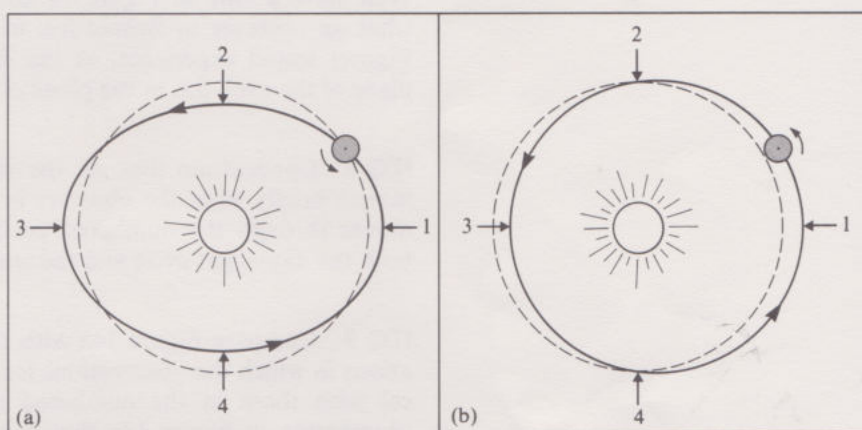


FIGURE 13 An attempt to explain the seasons by (a) altering the shape of the Earth's orbit, or (b) shifting the orbit so that the Sun is no longer at its centre. In both cases, the dashed line shows the unmodified orbit.

- ☐ Would it make any difference if the Earth and the Sun changed places in Figure 13, so that the Earth was at the centre and the Sun orbited round it?
- No, it would make no difference, because after the bodies had changed places, their separation would remain the same.

ITQ 7 Follow the progress of the Earth through the arrowed positions in Figures 13a and 13b, and identify the season you would expect the Earth to experience at each of them.

So far so good. But what about the fact that different parts of the Earth experience *different* seasons *at the same time*? There is no way that this can be explained by the modifications to the orbit shown in Figures 13a and 13b. Indeed, we seem to have reached an impasse. On the one hand, some evidence suggests that the orbit ought to be circular, or at least very nearly so, whereas other evidence seems to indicate that some parts of the Earth are nearer to the Sun than others. Surely, this is impossible?

Well, not quite. There is still one important aspect in the relative configuration of the two bodies that has not been taken into account properly. You probably know what it is, or can easily guess. It is the relative orientation of the Earth's axis of rotation to the plane of the Earth's orbit.

In all previous discussions, and particularly in Figures 11 and 13, the Earth's axis of rotation was *assumed to be perpendicular to the plane of the orbit* (of the Earth or of the Sun). Perhaps this assumption was wrong? What if the axis of rotation is actually oriented so that it lies *within the plane* of the orbit? Would that make any difference?

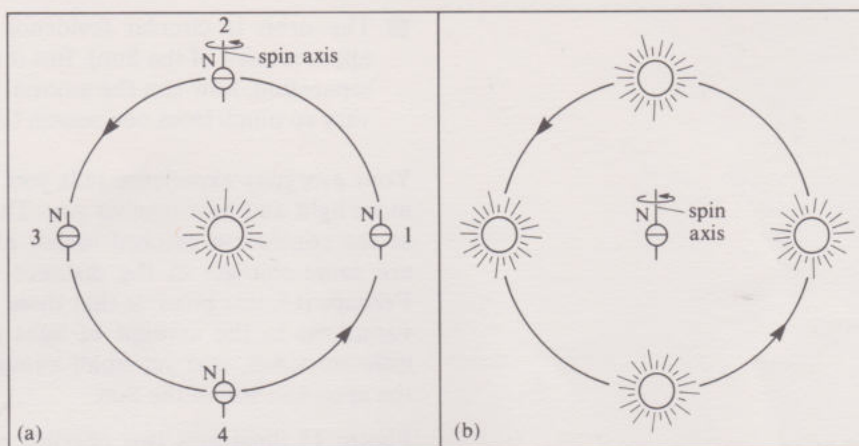


FIGURE 14 Can the axis of rotation lie in the plane of the orbit? (a) The Earth orbiting the Sun; (b) the Sun orbiting the Earth.

Well, have a look at Figure 14 and answer ITQs 8 and 9 by considering what an observer in Britain (i.e. in the northern Earth hemisphere in the Figure) would experience, as the Earth spins about an axis lying in the plane of the orbit (i.e. in the plane of the paper).

ITQ 8 Concentrate first on the situation depicted in Figure 14a. Summarize briefly what the observer in Britain would experience as the Earth moves through the numbered positions indicated on the orbit. Consider both the day–night cycle and the seasonal variations.

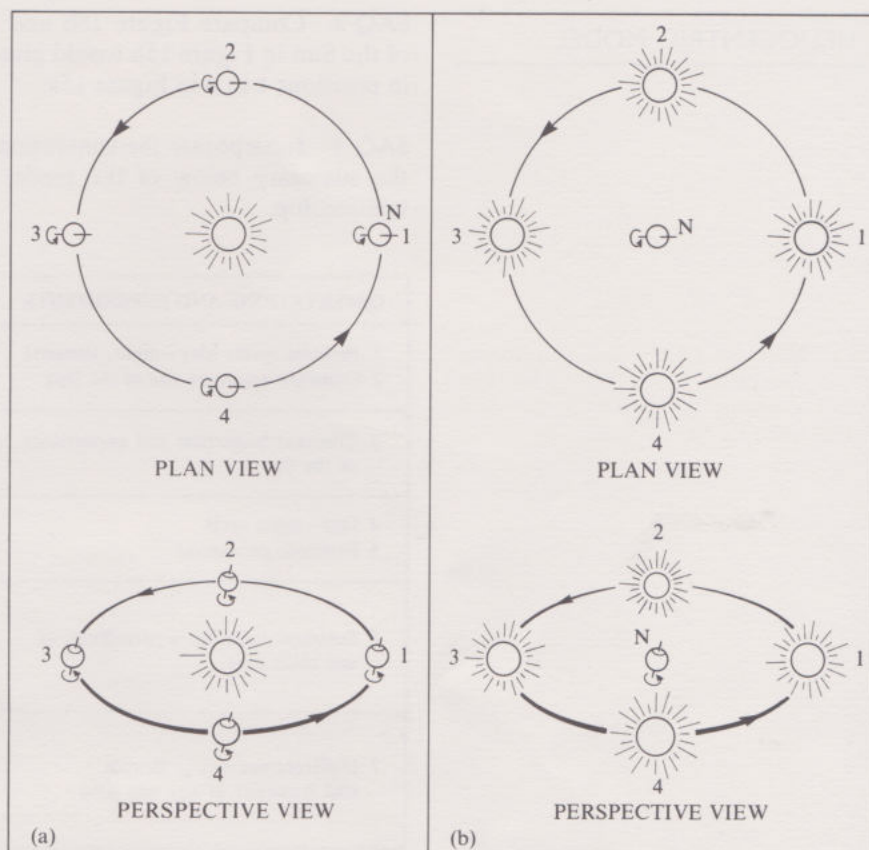
ITQ 9 Compare Figure 14a with 14b, and identify in Figure 14b the situations in which the observations for an observer in Britain would be identical with those in the numbered positions in Figure 14a. Is there any observation in Figure 14a that could not be made by an observer in the Northern Hemisphere in Figure 14b?

Incidentally, you may well be wondering why the axis of rotation as shown in Figure 14 has *the same orientation in space* all the time, thus assuming different orientations with respect to the line connecting the two bodies. We do not want to go into detail about this, but it is generally true that just as the plane of swing of a freely suspended pendulum is fixed, so the axis of rotation of a freely spinning object is also fixed. If you have ever tried to spin a bicycle wheel on its axle, holding the axle in your hands, and then attempted to tilt the axis, you will have experienced the resistance of the wheel to this change. The more massive the body, and the faster it spins, the more difficult it becomes to change the direction of its axis of rotation. Hence a body spinning freely, that is without any rigid coupling to another body, will keep its axis of rotation fixed forever.

After that digression, let us return to our main problem: how can we account for the seasonal cycle and for the fact that it is different at different places on the Earth?

You have just seen that adjustments of orbits do not work (Figure 13). Changing the axis of rotation from a direction perpendicular to the plane of the orbit to a direction that lies within the plane does not work either (Figure 14). However, examination of some of the situations in Figure 14 should have reminded you of the observational evidence that there are places on the Earth where, for a certain part of the year, the Sun never rises and never sets. There are only two such areas; they are situated in opposite parts of the Earth, and their experience of polar days and polar nights is complementary. Since the spin of the Earth as a whole does not change (as witnessed by the regular day–night cycle at all other parts of the surface), the only possible explanation of this effect is that the axis of rotation is not perpendicular to the orbit, and nor does it lie within the plane of the orbit. It must be *tilted* at an angle somewhere nearer 90° than 0° to the plane of

FIGURE 15 If the Earth's axis of rotation is tilted slightly away from the perpendicular to the orbit, this can account for the seasonal cycle and its local variations. (a) The Earth orbiting the Sun; (b) the Sun orbiting the Earth. N indicates the Earth's Northern Hemisphere. Note that the lower half of the Figure gives *perspective* views, in which circular orbits appear elliptical.



the orbit (at 90° there would be no polar nights anywhere, see Figure 13, and at 0° they would be experienced over the whole hemisphere at the same time during the year, see Figure 14).

Later, from an independent piece of evidence, you will be able to confirm this conclusion and give a better quantitative estimate for the angle of the tilt. In the meantime, convince yourself, by studying Figure 15, that such a tilted axis of rotation can indeed account for the existence of seasons as well as for their local variations. (If you can't manage to picture it from Figure 15 — we don't all possess a good visual imagination — it might help if you push a knitting needle through the centre of an apple (to represent the Earth) and move the apple in a horizontal circle round an orange (representing the Sun). Keep the axis of tilt — the direction of the needle — constant and give the apple a spin on the needle at the various positions, to try and find which parts of the apple would have a 'view' of the orange. Even better, if you happen to have a globe mounted on a tilted axis, use this instead of the apple and knitting needle.)

SAQ 2 Deduce from Figure 15a which season would be experienced by an observer in the Northern Hemisphere (N), and which season would be experienced by an observer in the Southern Hemisphere, as the relative position of the Earth and the Sun changes from 1 to 4. Hence complete Table 3.

TABLE 3 For use with SAQ 2

Location of observer	Configuration			
	1	2	3	4
Northern Hemisphere	winter			
Southern Hemisphere		autumn		

HELIOCENTRIC MODEL

SAQ 3 Compare Figure 15b and Figure 15a and decide which positions of the Sun in Figure 15b would give rise to the same seasons as experienced in positions 1 to 4 in Figure 15a.

SAQ 4 Incorporate the conclusions of Section 4.1.3 into boxes 6 and 7 of the summary below of the model we are developing for the Earth–Sun relationship.

OBSERVATIONS AND EXPERIMENTS	FEATURES OF THE MODEL
1 Periodic cycles (day–night, seasons) 2 Constant apparent size of the Sun	Circular orbits
3 Constant brightness and appearance of the Sun	Spin of the Sun non-existent or unimportant
4 Day–night cycle 5 Foucault pendulum	The Earth spins with a period of one solar day
6 Seasonal cycle has a periodicity of one solar year	
7 Different seasons in Britain and Australia at any one time	

4.1.4 WHICH OF THE TWO BODIES IS ORBITING — THE SUN OR THE EARTH?

So far, we have not resolved the question of which body — the Sun or the Earth — is in orbit around the other; options (b) and (d) (Figure 11) have consistently given the same results. (You have tested this, for example, on Figures 14 and 15.) Does this mean that for Earth-bound observers there is nothing to choose between the two models, or is there any observation that indicates that one of the models is superior to the other?

Well yes, there is. You may remember from Section 3 that if the position of a planet (for example, Mars) is plotted night by night with respect to a chosen constellation, the plotted path of the planet is not uniformly in one direction. Occasionally it appears that the planet reverses its direction for a while, before returning to its initial direction (Figure 8). This behaviour would be very odd indeed if we were to believe that the Earth is stationary and that the Sun as well as all the planets travel around it. There is no obvious reason why planets should have such complicated orbits; for example, there is no other large body anywhere near them that could temporarily deflect them from their original paths.

Could this strange behaviour be explained in a simple way if we were to use a model in which the Sun is stationary and is orbited by the planets (including the Earth)? This model is normally called the **heliocentric model** (*helios* is the Greek for Sun); but it is also referred to as the Copernican model after the Polish astronomer Nicolas Copernicus (1473–1543), who worked out in detail the motions of all the planets around the Sun.

The heliocentric model does indeed offer a very simple explanation for the retrograde motion of the planets. Figure 16a shows a heliocentric orbit of the Earth and a part of the orbit of another planet, say Mars. Numbers 1–9 correspond to simultaneous positions of the two planets. (To save space, the motion of Mars is shown 'slowed down'. In reality, Mars would cover about one-half of its orbit during one orbital period of the Earth. This does not change the principle of the explanation — you could think of the second orbit as that of a planet much farther away from the Sun than Mars,

WHY IS IT ODD

THIS IS PRE-PRESUMING
MASS ATTRACTION ETC

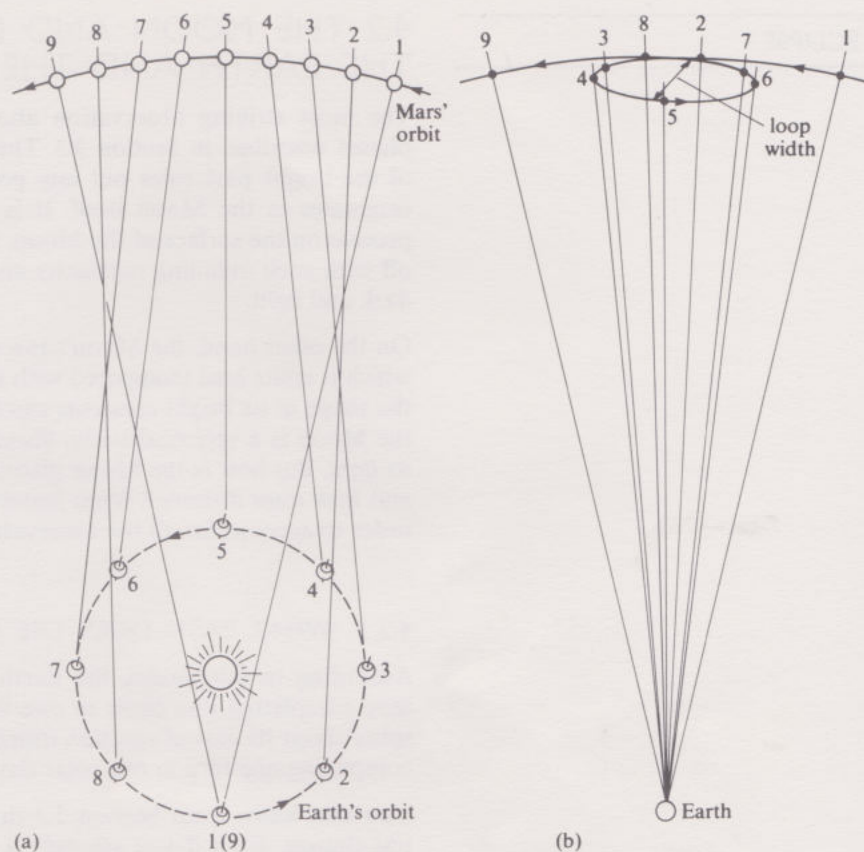


FIGURE 16 The orbit of the planet Mars.

(a) How we should see the motion of the two planets Mars and Earth with respect to the Sun, if we could look down on them from some distant point in space. Arcs 1–2, 2–3, 3–4, etc., in both orbits, represent the motion during the same fixed time intervals.

(b) The path of Mars as seen from one point on Earth. Earth-bound observers perceive that they are stationary, and therefore all the observations have been represented as if they had been made from one point on a stationary Earth, but with the directions unchanged from those in (a).

if you prefer.) The lines 1–1, 2–2, 3–3, etc. in Figure 16a define the *directions* in which the other planet is seen from the Earth, against the distant background of the stars.

When all these directions are transferred to a single point (Figure 16b), you can see that to Earth-bound observers (who believe themselves stationary) the other planet moves from right to left at first (1 → 2 → 3 → 4), but then *reverses* its direction of motion (4 → 5 → 6), before resuming the original direction again.

Thus the heliocentric model offers a simple and natural explanation of retrograde loops: they result from a *combination* of two circular orbital motions. There is no need to look for any ‘unknown’ influence, as would be required in a geocentric model.

The loop width, indicated by an arrow in Figure 16b, arises from the difference between the orbital planes of the Earth and the other planet. For the sake of clarity, the loop width has been exaggerated. If all the planets orbited in exactly the same plane, the retrograde motion would not be a loop: it would appear simply as a back-tracking along the planet’s previous path. The phenomenon of retrograde motion is illustrated further in the TV programme associated with this Unit.

In conclusion, we have found a good reason to prefer the heliocentric (Sun-centred) model to the geocentric (Earth-centred) model: the motion of the planets is very much simpler if the Sun, rather than the Earth, is taken to be the centre of the whole planetary system.

ECLIPSE

4.2 THE MOON AND ITS RELATIONSHIP TO THE EARTH AND THE SUN

The most striking observation about the Moon is the periodic cycle of phases described in Section 3.3. The continuously changing shape and size of the bright part rules out any possibility that the light from the Moon originates in the Moon itself. It is very difficult to imagine any physical process on the surface of the Moon, that could switch different parts on and off with such unfailing regularity and with such a sharp boundary between dark and light.

On the other hand, the Moon's low overall brightness, the negligible rate at which it emits heat (compared with the corresponding rate for the Sun), and the shape of its bright crescents can be readily understood by assuming that the Moon is a spherical body, *illuminated by the Sun and reflecting some of its light*. But how is the Moon placed with respect to the Sun and the Earth, and how does it move? What features should a three-sphere model have in order to account for all the observations?

4.2.1 WHAT PATH DOES THE MOON FOLLOW?

According to our model, the Earth moves in a circular orbit around the Sun, completing one circle in one year. As it goes around the Sun, it also spins about its axis of rotation (tilted with respect to the plane of the orbit), completing one turn in one solar day.

You also know from Section 3.3 that the apparent size of the Moon does not change. Even if you see only a narrow bright crescent, if you were to complete the circle that corresponds to the crescent, the size of the circle would be the same as that of the full Moon. Thus the distance between the Earth and the Moon must be *constant*. And there are only two ways in which this could be true. Either the Moon moves alongside the Earth in a concentric circle around the Sun, or else it moves in a circular orbit *around* the Earth and at the same time accompanies the Earth in its orbit around the Sun.

The first possibility is easily discounted. Can you see why? Look at Figure 17. In this configuration, there would be no lunar phases. The Moon would look the same at all times to an observer at any one place on the Earth, although it would look different to observers at different places. You might like to try to imagine how you would see the Moon if you were sitting somewhere in the Northern Hemisphere of the Earth and if the Moon were moving alongside the Earth. Consider six different possibilities for the position of the Moon: inside or outside the Earth's own orbit, and, for each of these, ahead, behind or exactly on the Sun–Earth line (Figure 17).

So, in order to account for the lunar phases (Figure 7), the Moon must be moving *around* the Earth. And since the whole cycle of the phases has a period of about 28 solar days, this is likely to be the time it takes the Moon to complete one circle around the Earth.

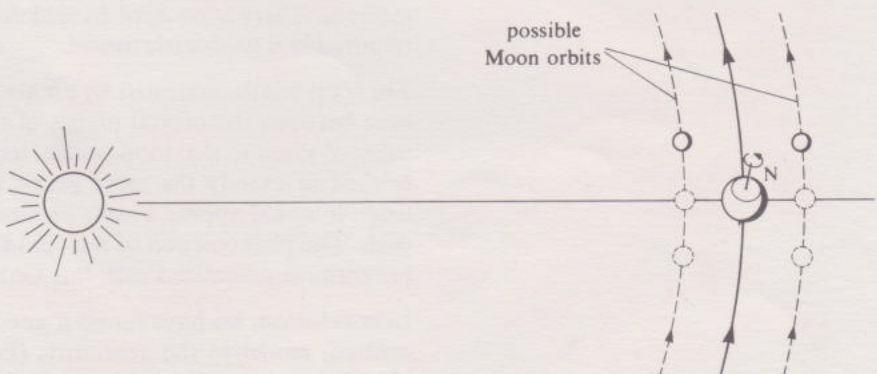


FIGURE 17 Can the Moon travel *alongside* the Earth?

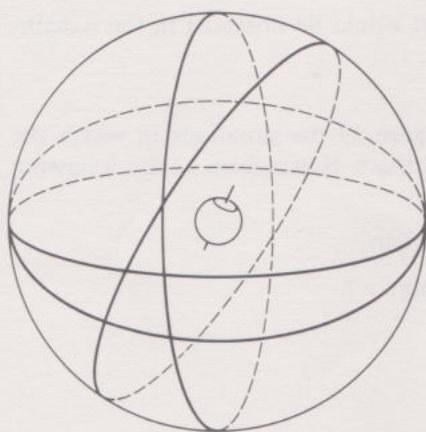


FIGURE 18 A sphere is defined by all possible circular orbits with a common centre and equal radius. (Note that the 'dashed' parts of the orbits define the 'invisible' half of the sphere.)

4.2.2 WHAT IS THE PLANE OF THE LUNAR ORBIT?

Having established that the Moon cannot simply travel parallel to the Earth but must move around it in a circular orbit, it is pertinent to ask: How is the lunar orbit related, in space, to the orbit of the Earth? This is not a trivial question, as you can see from Figure 18: there is an infinitely large number of different circular orbits with the same centre point and of the same diameter, all lying on one spherical surface surrounding the Earth. Since we cannot tell which is the most likely orbit, we may as well start by looking at two distinct options and comparing how they could account for our real observations.

Let us first assume that the plane of the lunar orbit is *identical* with the plane of the Earth's orbit. Imagine yourself to be somewhere in the Northern Hemisphere of the Earth (Figure 19) and consider how and when you would see the Moon as it travels around. (Remember, both the Earth's orbit and the lunar orbit lie in the plane of the paper.)

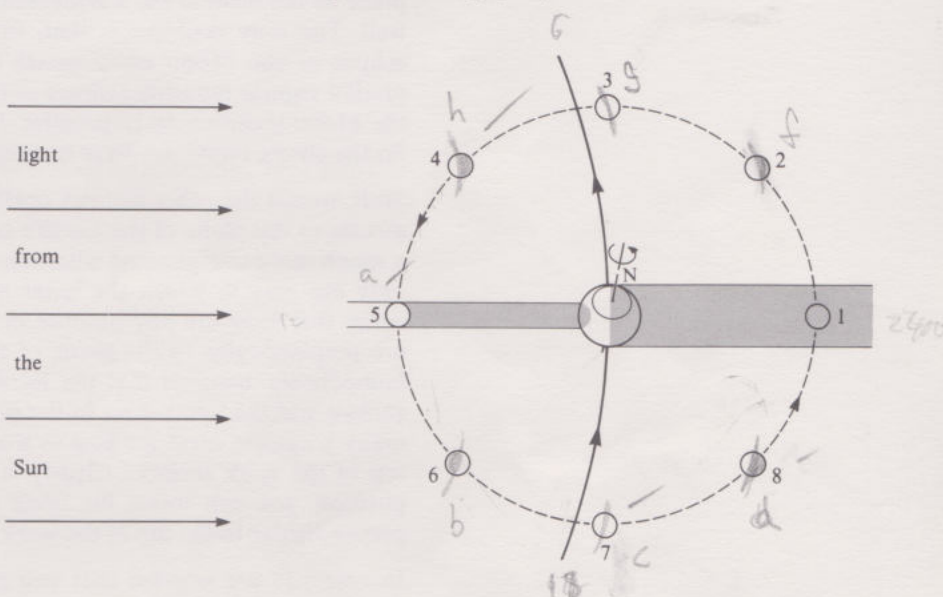


FIGURE 19 What happens if the orbit of the Moon lies in the same plane as the plane of the Earth's orbit?

- (a) new Moon
- (b) waxing crescent
- (c) first quarter
- (d) waxing gibbous
- (e) full Moon
- (f) waning gibbous
- (g) last quarter
- (h) waning crescent
- (i) new Moon

FIGURE 20 Phases of the Moon.

When you are trying to imagine how you would see the Moon during each day (one spin of the Earth), you should note that the orbit of the Moon in Figure 19 (as well as in the later Figures) is *not drawn to scale*. The distance of the Moon from the Earth is about 30 times the diameter of the Earth — to draw this relationship to scale would be somewhat wasteful of paper! But because of this large distance, the *appearance* of the Moon will not change appreciably between, say, the evening and morning, although the observer's position has changed as the Earth spins. If you are finding it hard to visualize the likely appearance of the Moon, you will receive considerable help from the TV programme associated with this Unit.

Now try the following three ITQs, in which you will use the idea of **eclipses** — the total or partial obscuring of one celestial body by another. These ITQs are quite demanding, so don't worry if you find them difficult!

ITQ 10 Complete each of the statements (i)–(iv) below with one of the Moon's (numbered) positions shown in Figure 19. You will probably find it helpful to refer to Figure 20, which reminds you of the names of the Moon's phases.

- (i) The Moon is in the waxing crescent phase (b) when in position4....
- (ii) The Moon is eclipsed by the Earth when in position1.....
- (iii) The Moon is in the last quarter (g) when in position3.....
- (iv) The Moon is in the waning gibbous phase (f) when in position2.....

ITQ 11 Describe the lunar phases that would be observed in the remainder of the positions shown in Figure 19.

ITQ 12 Identify by numbers from Figure 19 the situations in which the Moon is above the horizon in the Northern Hemisphere at the following times:

- (i) the afternoon and first half of the night; ✓
- (ii) most of the night and early morning; 2✓
- (iii) all day; 3✓
- (iv) the evening and most of the night. 4✓

It is very encouraging to see that this choice of the lunar orbit (in the same plane as the orbit of the Earth) seems to reproduce the cycle of phases quite well. The only problem is that, from Figure 19, you would expect a full eclipse of the Moon *every month* (position 1). And similarly you should predict regular monthly eclipses of the Sun, when it is covered by the disc of the Moon (position 5). In practice, however, eclipses are much less frequent. So the choice could not have been quite right after all.

Well, would the other distinct option, namely that of a lunar orbit *perpendicular* to the plane of the Earth's orbit, do any better? At first sight, this is a much more complicated situation than before. Can you see why? There is only *one* way in which the lunar orbit can lie in the plane of the Earth's orbit. But there are any number of different planes for the lunar orbit that are perpendicular to the plane of the Earth's orbit. If you cannot see this immediately, imagine that the Earth's orbit lies in the plane of your work surface and the lunar orbit in the plane of the front cover of this Unit. How many ways are there for you to make the front cover perpendicular to the top of the work surface? Clearly, if you start from one such perpendicular position, you can rotate the book through a full circle and it will remain perpendicular to the top of the work surface all the way round.

In case you are worried that you are going to be asked to go through an endless number of plane orientations, don't despair. All of them can be eliminated in a stroke!

Look at Figure 21. This shows, in a perspective drawing, the plane of the Earth's orbit and an arbitrarily chosen, perpendicular lunar orbit. If you were an observer in the Northern Hemisphere, would you see the Moon, if only for a short while, during *every* spin of the Earth (each solar day)?

Clearly not, because for one-half of its way around the Earth (that is for some 14 days or so) the Moon would remain below the level of your horizon (between positions 5–6–7–8–1, i.e. the part of the orbit shown with a dashed line to indicate it is below the plane of the Earth's orbit and therefore 'out of sight'). This would be true, whichever way you turned the plane of the lunar orbit, as long as it remained perpendicular to the plane of the Earth's orbit. And this is in contradiction with our experience, for the Moon is above the horizon, at some time or other, during *every solar day*. Thus, whatever the orientation of the lunar orbit in space, it cannot be perpendicular to the plane in which the Earth travels around the Sun. In fact, the observation that the Moon is never below the horizon for more than part of a solar day at a time, clearly supports the conclusion that the plane of the lunar orbit cannot be *very* different from the plane of the Earth's orbit, although it cannot be *quite* identical with it, as you saw before.

Let us check whether a *slightly inclined* lunar orbit, as in Figure 22, can cure the problem of having too many eclipses. Note that this Figure is a *perspective* drawing, with circular orbits shown as ellipses; this is necessary to convey the impression of their relative inclination. Note also that although one-half of the lunar orbit (the part shown with dashed lines) is now below the plane of the Earth's orbit, the inclination is sufficiently small

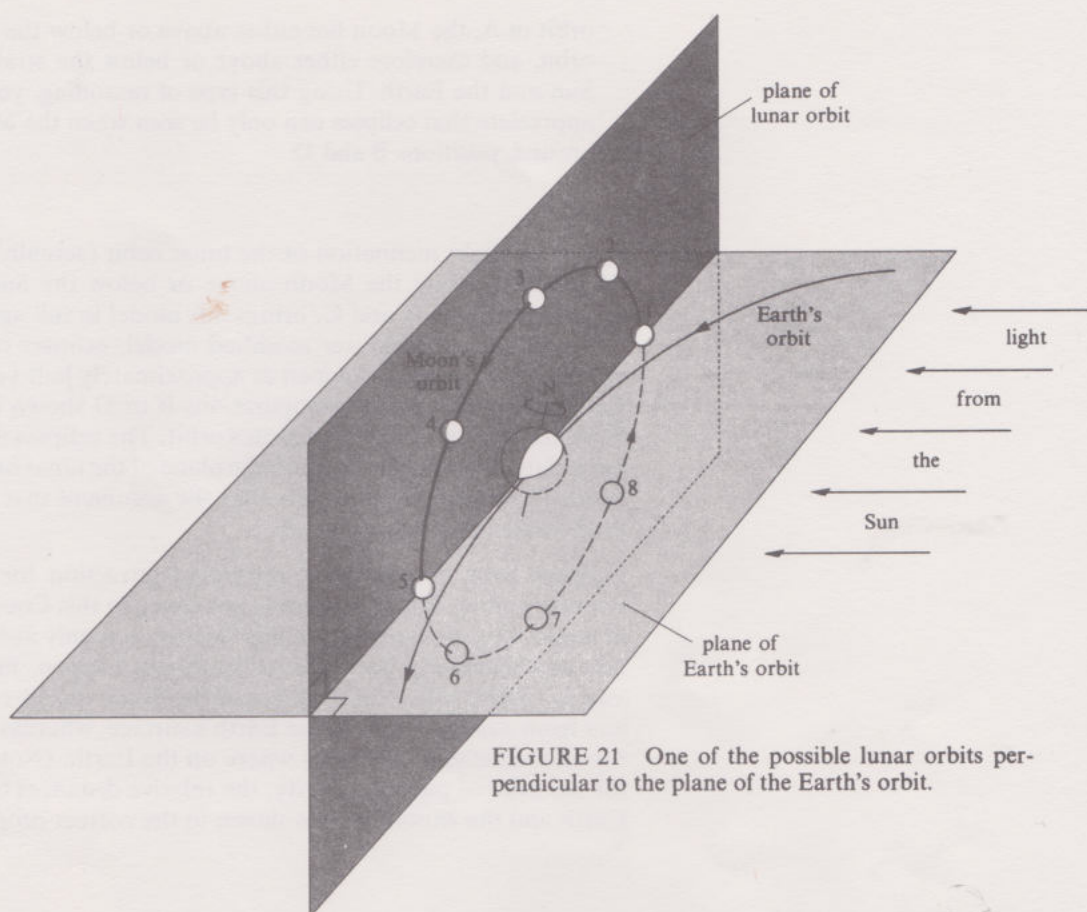


FIGURE 21 One of the possible lunar orbits perpendicular to the plane of the Earth's orbit.

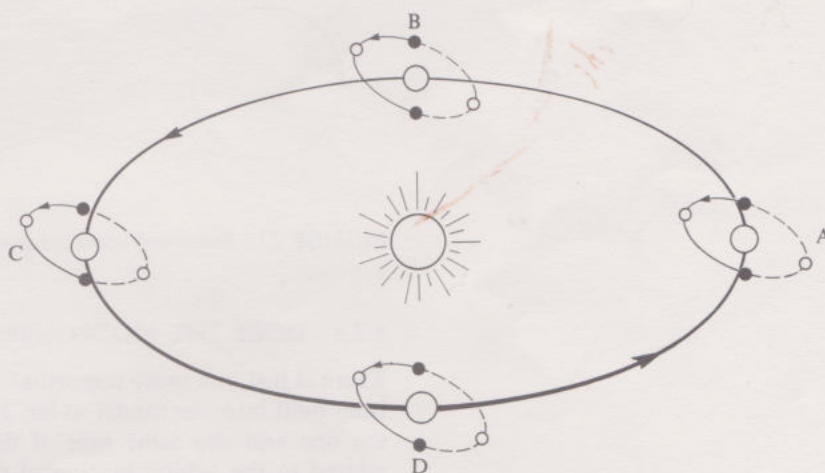


FIGURE 22 What happens if the lunar orbit is slightly inclined to the plane of the Earth's orbit? In each of A-D, the dashed part of the lunar orbit is *below* the plane of the Earth's orbit. Solid circles: Moon in the plane of the Earth's orbit; open circles: Moon above or below the plane of the Earth's orbit (therefore there cannot be an eclipse of the Sun or the Moon).

for the Moon to remain visible from the Northern Hemisphere even at the lowest point of its orbit. This is helped by the fact that the Earth's axis of rotation is also inclined with respect to the plane of the Earth's orbit.

- ☐ Can any eclipses of the Sun or the Moon occur when the Earth is in position A?
- ☒ No. An eclipse can occur only if the Sun, the Moon and the Earth lie in a straight line. This cannot happen in A, because the two points at which the lunar orbit crosses the plane of the Earth's orbit (the two points shown as solid circles at A in the Figure) lie far away from the line that connects the Sun to the Earth. At all other points on the lunar

orbit in A, the Moon lies either above or below the plane of the Earth's orbit, and therefore either above or below the straight line joining the Sun and the Earth. Using this type of reasoning, you should be able to appreciate that eclipses can only be seen when the Moon's orbit is in, or around, positions B and D.

So a very slight inclination of the lunar orbit (actually by about 5.2°), just sufficient to bring the Moon above or below the Sun–Earth line in and around positions A and C, brings our model in full agreement with observations. According to our modified model, eclipses cannot happen every month, but they must happen at approximately half-yearly intervals, when the three bodies are in configurations B or D shown in Figure 22 and the Moon is in the plane of the Earth's orbit. The eclipses do not happen on the same dates every year, because the plane of the lunar orbit is not completely fixed. However, this does not alter the argument that they happen twice a year, rather than every month.

Eclipses have considerable emotional attraction for scientists and non-scientists alike, but alas there is not space in this Course to consider them in detail. For the purposes of this Course, you only need to understand why and approximately how often eclipses can happen. Figure 23 should help you to realize why a total eclipse of the Sun is visible only for a short while and from a limited area of the Earth's surface, whereas a total eclipse of the Moon can be seen from any where on the Earth. (Note that in this Figure, for the sake of pictorial clarity, the relative distances between the Sun, the Earth and the Moon are not shown in the correct proportion.)

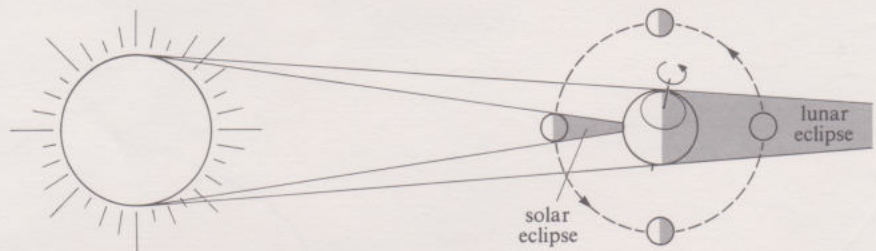


FIGURE 23 Solar and lunar eclipses.

4.2.3 DOES THE MOON SPIN?

There is just one more important observation about the Moon that has not been built into our model so far. How is it that from the Earth we only ever see one and the same side of the Moon? How can this observation be related to the orbital motion of the Moon that had to be introduced into our model in order to account for the cycle of phases? Your first thought might be to say that the Moon does not spin.

- ☐ Why can we rule out straight away the suggestion that the Moon does not spin at all?
- ☒ Because we always see the same face of the Moon. If the Moon did not spin, it would always be oriented the same way in space; for example, a particular feature on the surface would constantly face towards one and the same star. Because the Moon is moving around the Earth, an Earth-bound observer would see the whole surface of the Moon during a lunar month. (Try turning in a circle with an apple held at arm's length, while keeping the stalk of the apple pointing towards, say, the top of a door so that the apple is always oriented the same way in space.)

So, given that the Moon is spinning, what can we deduce about the Moon's axis of rotation and about the period of its spin?

ITQ 13 Select from the key below the *two* statements that, taken together, are capable of explaining why we always see the same face of the Moon from the Earth. Explain why the other statements cannot be correct.

KEY for ITQ 13

- A The axis of rotation lies in the plane of the lunar orbit, and always points towards the Earth ✓
- B The axis of rotation lies in the plane of the lunar orbit, and its direction is fixed in space
- C The axis of rotation is roughly perpendicular to the plane of the lunar orbit
- D The period of spin is exactly equal to the orbital period of the Moon ✓
- E The period of spin of the Moon is the same as the Earth's period of spin
- F The period of spin is the same as the Earth's orbital period

4.2.4 SUMMARIZING THE MOON'S PLACE IN THE MODEL

You are now in a position to review the important features of the Moon's relationship to the Earth and the Sun. If you wish to do so now, try SAQ 5. Alternatively, you might want to return to the question later, as a form of revision.

SAQ 5 There are two sets of statements below. One set lists nine observations relating to the Moon as seen from the Northern Hemisphere of the Earth. The other set lists features (a)–(d) of a model three-body system representing the Sun, the Earth and the Moon. Indicate for each feature (a)–(d) the observations (1–9) that are relevant to each particular feature.

Observations

- 1 The Moon is visible at different times during the day and/or night.
- 2 The time at which the Moon is visible is closely related to the shape and size of its bright part (phases).
- 3 The Moon is much less bright than the Sun and emits a negligible amount of heat.
- 4 The complete cycle of lunar phases has a period of about 28 solar days.
- 5 The Moon is visible, albeit at different times, for some part of each solar day (provided that it is not obscured by clouds).
- 6 The Moon shows the same face to the Earth at all times.
- 7 The Moon is always of the same apparent size.
- 8 The apparent size of the Moon is about the same as that of the Sun.
- 9 Eclipses of the Moon occur relatively rarely (no more than twice a year).

Features

- (a) The Moon is a spherical body reflecting the light from the Sun. Choose *two* observations. 2 3
- (b) The Moon moves around the Earth in a circular orbit. Choose *four* observations. 4 1 5
- (c) The plane of the lunar orbit is slightly inclined with respect to the plane of the Earth's orbit. Choose *two* observations. 9 5
- (d) The Moon spins with a period equal to the period of its orbital motion, the axis of rotation being roughly perpendicular to the plane of the orbit. Choose *two* observations. 6

4.3 THE EARTH AND THE STARS

During each night the stars appear to move in circles, all in the same direction and always at the same relative distances from each other (the shapes of constellations do not change). In the Northern Hemisphere this rotation takes place about a fixed point, the star Polaris.

Since you already know that the Earth spins about an axis of rotation whose direction is fixed in space (Sections 4.1.2 and 4.1.3) and that this spin explains the apparent circular path of the Sun, it is only natural to assume that the apparent rotation of the stars is also explained by the spin of the Earth.

- ☐ Can you think of a simple experiment by which this assumption can be tested?
- You could, for example, set a photographic camera on a firm support and point it so that Polaris was at the centre of the field. Then if you were to leave the shutter open for a sufficiently long time — at least four hours — you would obtain a photograph looking something like Figure 24. The lengths of the curved tracks depend on the time of exposure.

ITQ 14 Select one of the more distinct tracks in Figure 24 and estimate approximately what fraction of a full circle it represents. From this, decide what exposure would, in your view, produce such a picture: 2 hours, 4 hours, 8 hours, 12 hours, or 24 hours.

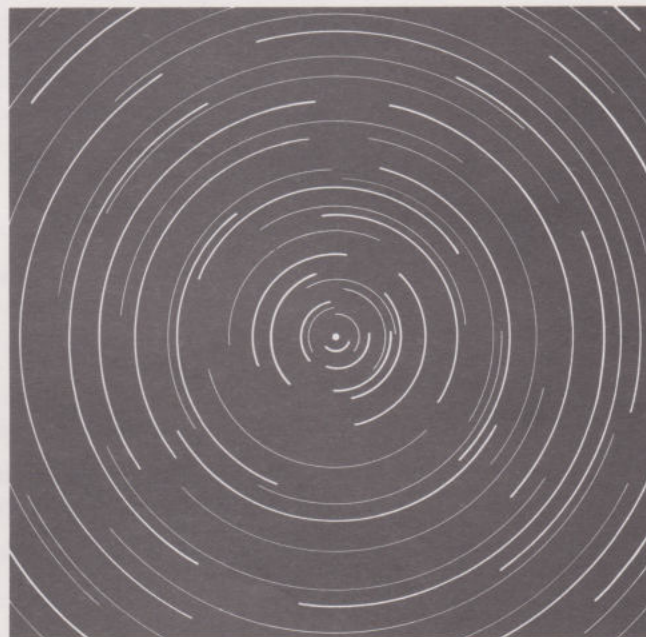


FIGURE 24 A photograph of the night sky, with Polaris at the centre, taken with a long time-exposure to show the motion of the stars. (Note that in order to increase the clarity of this copy, some bright tracks were emphasized and many weaker tracks were suppressed.)

The observations that *all* star tracks on the photograph are concentric circular segments and that each segment is *the same fraction* of a full circle, support the assumption that the apparent motion of stars is due to the spinning of the Earth. If that is so, then the only possible explanation for the fact that Polaris never moves is that *Polaris lies exactly in the direction of the Earth's axis of rotation*.

We can now combine this conclusion with the previous result derived in Section 4.1.3. In order to explain the seasonal cycle within one year and its local variations at different parts of the Earth's surface, it was necessary to

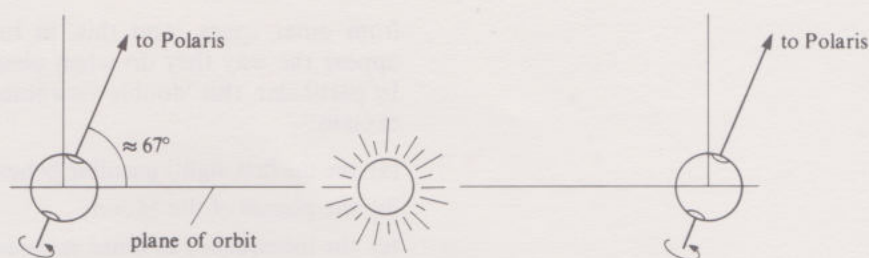


FIGURE 25 The Earth's axis of rotation points permanently to Polaris.

accept that the axis of rotation is tilted with respect to the plane of the orbit. In fact, for the best agreement with all observations the axis must be at an angle of about 67° to the plane of the orbit (Figure 25). Now we know that this direction is also the direction to Polaris.

SUMMARY OF SECTION 4

In this Section, we have developed a model of the relationship between the Earth, the Sun and the Moon, in order to account for the experimental observations discussed in Section 3. Here is a summary of the model.

- 1 The Sun, the Earth and the Moon are spherical bodies.
- 2 The Sun radiates light and heat evenly from every part of its surface (hence spin would not be noticeable, even if it exists).
- 3 The Earth spins about its axis of rotation and this accounts for the day-night cycle.
- 4 The Earth orbits around the Sun in a circle and one complete circle corresponds to one complete seasonal cycle (one year).
- 5 The Earth's axis of rotation is inclined at about 67° to the plane of its orbit, remains fixed in space and points towards the star Polaris. The tilt of the axis of rotation accounts for seasonal variations.
- 6 The Moon reflects sunshine and it moves around the Earth in a circular orbit. During one orbital period (one month), the Moon goes through a cycle of phases; these can be explained by its relative positions with respect to the Sun and the Earth.
- 7 The plane of the lunar orbit is slightly inclined with respect to the plane of the Earth's orbit. This explains the times at which the Moon is observed above the horizon as well as the frequency of eclipses.
- 8 The Moon spins about its axis of rotation, which is perpendicular to the plane of its orbit, and the period of its spin is exactly equal to the period of its orbital motion around the Earth. This explains why the same face of the Moon is seen at all times on Earth.

5 TV NOTES: THE PLANET EARTH — A SCIENTIFIC MODEL

It is not very easy to visualize the three-dimensional relationship between the various bodies that orbit the Sun. In such a situation, it is helpful to construct a three-dimensional model of the system; we can then 'look down' on the model and explore its behaviour from an external viewpoint. That is what is done in this TV programme. As you will see, this is a particularly useful approach to adopt in trying to understand the Solar System, as it helps us to escape from our Earth-bound viewpoint (or 'frame of reference') and see, in our mind's eye, the workings of the Solar System

S₁ Z Means degree variation from the (degree of inclination)

from outer space. And this, in turn, helps us to understand why things appear the way they do when observed from our spinning, orbiting Earth. In particular, this 'double viewpoint' approach is used in the programme to explain:

- (a) the (at first sight) peculiar behaviour of a Foucault pendulum;
- (b) the phases of the Moon;
- (c) the infrequency of lunar eclipses;
- (d) the 'retrograde' motions of planets.

When viewed from the 'frame of reference' of a rotating roundabout, the motion of a swinging pendulum (attached to the roundabout) appears very strange; the plane-of-swing of the pendulum appears to be continuously changing. This point is demonstrated in the opening sequence of the programme. However, when the pendulum is viewed from a *stationary* frame of reference relative to the roundabout, it can be seen that the plane-of-swing of the pendulum is fixed. The apparent change of the plane-of-swing (as seen from the roundabout) is a consequence of the roundabout's rotation. This is the basic principle underlying the operation of a Foucault pendulum. The programme demonstrates that the plane-of-swing of a pendulum suspended directly over the Earth's North Pole remains fixed *with respect to the stars*. If the Earth is spinning, an observer attached to the Earth will see an apparent rotation of the plane-of-swing. Conversely, if the plane-of-swing of a suspended pendulum appears to rotate, then we can deduce that the Earth is spinning. In the programme, we show you a modern reconstruction of this classic experiment (first performed in 1851 by the French physicist Leon Foucault). Our pendulum was suspended from the dome of St Paul's Cathedral in London (Figure 26). The experiment is not as simple to set up as you might think. We had to take all kinds of precautions to ensure that the rotation of the plane-of-swing was genuinely caused by the Earth's spinning motion, and not by bias in the suspension, by 'twist' in the suspension cable, or by a small sideways motion imparted to the pendulum bob at the time of release.

We show that, in London, the plane-of-swing rotates at the rate of about 12° per hour. This means that it takes $(360^\circ/12^\circ)$ hours = 30 hours for a rotation through a complete turn of 360° . (The rate is exactly 15° per hour — 24 hours for 360° — at either the North or South Pole and decreases to zero at the Equator.)

The programme then goes on to examine the phases of the Moon. By building a model of the Earth–Moon system, and by simulating the sunlight with a distant arc lamp in the studio, we are able to compare the view of the



FIGURE 26 Performing the Foucault experiment in St Paul's Cathedral; Mike Pentz, former Dean of Science at the Open University, is on the left, and the Dean of St Paul's on the right.

'Moon' (as seen from a camera positioned on the 'Earth'), with the view of the whole system as seen from a camera positioned in 'outer space'. It is then possible to see that the full-Moon and new-Moon phases occur when the Sun, Earth and Moon are all aligned in the same plane, whereas half-Moon (that is, the first or last quarter) occurs when the angle between the Sun and the Moon (as measured from the Earth) is a right angle (90°).

However, this simple method leads to the prediction that a lunar eclipse should occur every month. Lunar eclipses are not nearly as frequent as this, so the model needs to be modified. We show that the inconsistency can be removed by *inclining* the plane of the Moon's orbit about the Earth. Lunar eclipse positions are much less frequent according to such a model.

Finally we move outwards from the Moon, to the planets of the Solar System. And again we use the 'double viewpoint' approach to help explain the phenomenon of retrograde motion.

6 CONCLUDING REMARKS

If you were now to ask yourself what you have learnt from this Unit, the answer would depend far more on your previous knowledge than on what you have read here. Perhaps you found no new information at all. If so, remember that the communication of information was not the main purpose of the exercise. We wanted, above all, to convey to you something of the way in which science develops. In this Unit, you have repeatedly seen examples of the process first described in Section 1.2. By working on observations or experience, the human imagination creates a trial explanation or theory. Sometimes, it even provides more than one theory, and the different possibilities then compete for our allegiance. Let us recall some examples.

You saw the process in action in Section 2 with the pancake and spherical models of the Earth, and in Section 4.1 with the four options for the relative motion of the Earth and Sun. It recurred again in Section 4.1.3 with attempts to explain the seasonal cycle, either by modification of the Earth's orbit in our model or by tilting the Earth's axis of rotation. In Section 4.2, imagination first offered a choice between a Moon moving alongside or in orbit around the Earth, and then between various orientations of the Moon's orbit with respect to the Earth's orbital plane. All these different theories were essentially descriptions of models of the type first mentioned in Section 1.2.1.

What happened after these different theories were introduced? In all cases, further observations or experiences were drawn into the discussion. Sometimes these flatly contradicted deductions that could be made from some of the theories, but were consistent with conclusions that could be drawn from others. Thus some of the theories could be falsified and others corroborated, as described in Section 1.2. Progressive falsification of the competing models continued through the Unit until, at this stage, just one has survived.

It is important to note that the simple model described in the Summary of Section 4 is not consistent with *all* the relevant observations that have ever been made, only with those we have introduced so far. As soon as one takes a more careful look, using accurate measuring instruments, the model has to be refined. Thus the Earth is not perfectly spherical, although this is not apparent from mere inspection of the photograph at the beginning of the Unit. Likewise the Earth's orbit is not exactly circular, although the deviation from a circle would not be noticeable if the orbit were reduced to the size of this page.

By now, however, none of this should surprise you. In Section 1.2.1, you were told that models are often constructed for narrow purposes, and this model has coped adequately with all the observations that have concerned us until now. And as was stressed in Section 1.2.1, science does not claim that its theories are true; they are retained provisionally until new evidence turns up to prove them inadequate.

SOLAR SYSTEM

Finally, a few words on Section 4.1.4, where a choice was made between two competing models, even though neither of them had been falsified by experience: the heliocentric model was preferred to the geocentric one. This choice was made because in the geocentric model the observed retrograde loops in the planetary paths would mean real reversals of the direction of motion, for no apparent reason. The heliocentric model, by contrast, explains this observation by a very simple combination of two relative circular motions. Now in science, *one does not choose a more complicated explanation when a simpler one does the job equally well*. So the heliocentric model was preferred for its greater simplicity and elegance, or, dare we say it, for its beauty. It is illustrated in Figure 27, which shows schematically the bodies orbiting the Sun — the **Solar System**.

In a sense, therefore, the choice was an act of faith. And subsequently, that faith was fully justified. By putting the Sun at its centre, the model facilitated the huge imaginative leaps to the laws of planetary motion and gravitation. Those leaps are associated particularly with the names of Johann Kepler and Isaac Newton.

To understand their achievements, you need to delve further into the nature of science. Throughout this Unit, you have not used a single formula or equation. And yet, in a very broad sense, the derivation of the heliocentric model was mathematical, in that you were making choices between different options, and eliminating wrong ones by combining reasoning with new observations. This approach is fine as far as it goes, but it does not go far enough.

Our curiosity is not satisfied by knowing that the Earth goes round the Sun, and the Moon around the Earth. What about the sizes of the three bodies? How far apart are they? How fast do they move with respect to one another? These are *quantitative* questions. To answer them, one must make *measurements*, and begin to manipulate mathematical formulae. You will take this step in Unit 2, and it will give you the necessary background for you to understand the principles that explain the motions of *all* celestial bodies.

OBJECTIVES FOR UNIT 1

When you have completed this Unit, you should be able to:

- 1 Explain the meaning of, and use correctly, all the terms identified by bold type in the text. (These terms are also 'flagged' in the margins at the top of appropriate left-hand pages.)
- 2 Distinguish statements that are scientific from those that are not, according to the falsifiability criterion. (SAQ 1)
- 3 Describe what is meant by a periodic process, and be able to work out the period, given the appropriate data. (ITQs 2–5)
- 4 Describe the motion of the Earth with respect to the Sun. (ITQs 7–9; SAQs 2–4)
- 5 Describe the motion of the Moon with respect to the Earth and the Sun. (ITQs 10–13)
- 6 Explain local variations in the seasonal cycle. (ITQs 7–9; SAQ 2)
- 7 Explain the phases of the Moon. (ITQs 10–12)
- 8 Explain the apparent motion of the stars. (ITQ 14)
- 9 Correlate systematic observations (such as the sequence of seasons, lunar phases, etc.) with the features of a model. (ITQs 1 and 7–13; SAQs 2–5)

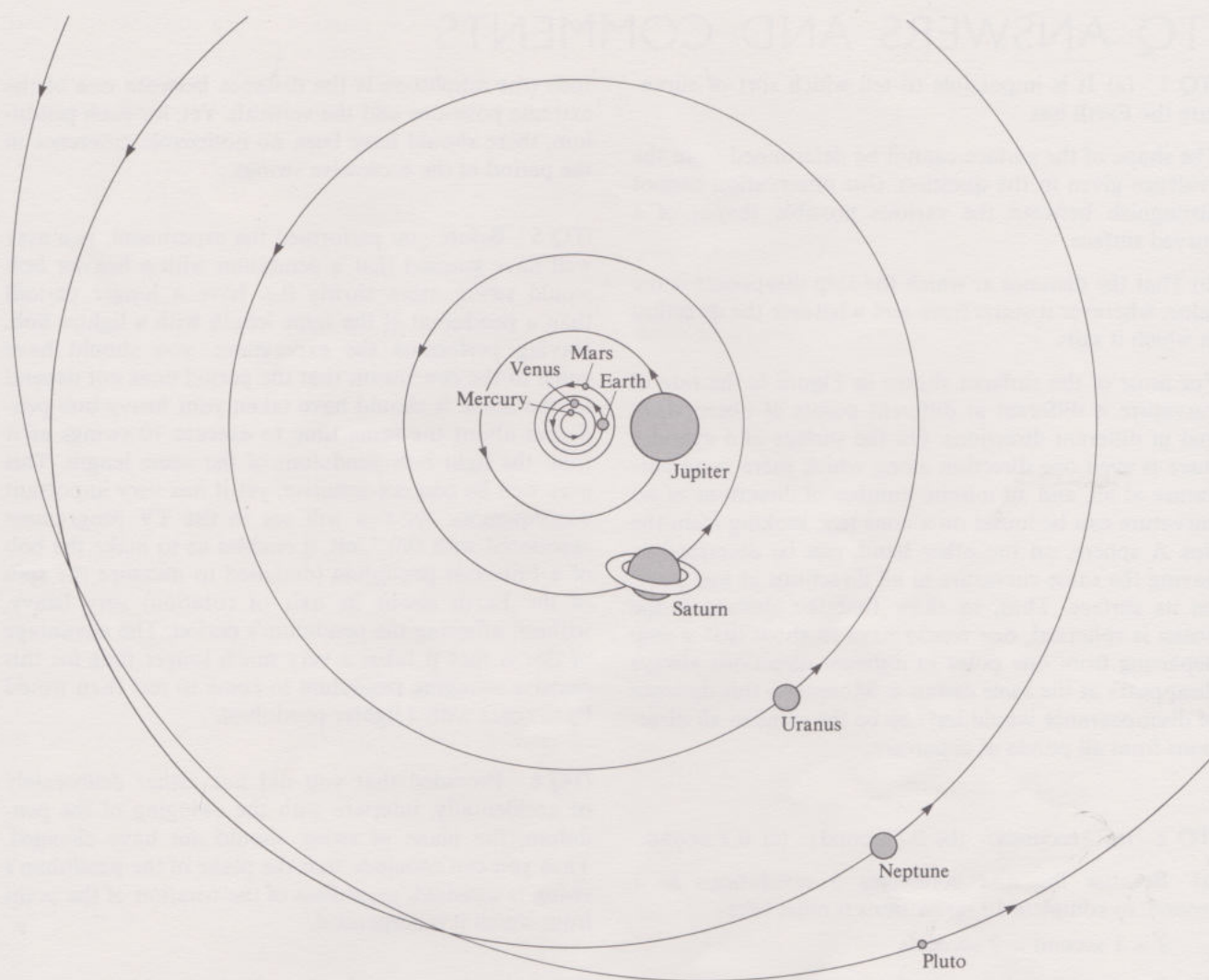


FIGURE 27 Schematic diagram of the Solar System. The diameters of the planets are shown in approximately the correct proportion to each other, as are the sizes of the orbits. However, the sizes of the orbits are *not* in correct proportion to the diameters of the planets. (If the orbits had been drawn on the same scale as the sizes of the planets, this page would have had to be more than 1 kilometre wide!) The diameter of the Sun is about ten times that of Jupiter, so the Sun could not be shown at the centre of this Figure; on the scale we are using for the planets, it would have covered up most of the Figure!

ITQ ANSWERS AND COMMENTS

ITQ 1 (a) It is impossible to tell which sort of curvature the Earth has.

The shape of the surface cannot be determined from the evidence given in the question. *One* observation cannot distinguish between the various possible shapes of a curved surface.

(b) That the distance at which the ship disappears is the same, wherever it starts from and whatever the direction in which it sails.

For most of the surfaces shown in Figure 6, the rate of curvature is different at different points of observation and in different directions. On the surface of a cylinder there is even one direction along which there is no curvature at all, and an infinite number of directions of no curvature can be found on a cone (e.g. looking from the tip). A sphere, on the other hand, can be described as having the same curvature in all directions at any point on its surface. Thus, to show that the surface of the ocean is spherical, one would have to show that a ship departing from one point in *different* directions always disappears at the *same* distance. Moreover, this distance of disappearance would have to be the same in all directions from all points of departure.

ITQ 2 (a) 2 seconds; (b) 0.2 second; (c) 0.2 second.

(a) Because the disc completes 5 revolutions in 1 second, to complete 10 revolutions it must take

$$2 \times 1 \text{ second} = 2 \text{ seconds}$$

(b) Because the disc completes 5 revolutions in 1 second, it must complete 1 revolution in

$$1 \text{ second}/5 = 0.2 \text{ second}$$

(c) The period of rotation of the disc is defined to be the time it takes to complete one revolution — 0.2 second, as you saw in part (b)!

ITQ 3 Shortening the pendulum reduces the time.

You should have found that the shorter the pendulum, the faster it swings (i.e. the more complete swings it executes in a given time). The time taken to execute 10 swings for a 1 metre pendulum is about 20 seconds. We shall not give you the times for the other two pendulums — we may ask you about them in one of the Unit's CMA questions!

ITQ 4 The shorter the pendulum, the shorter is its period.

Remember the period is defined as the time taken to execute one complete sequence of the periodic motion, in this case one complete swing. Hence, from the answer to ITQ 3, the period of the 1 metre pendulum is about $20 \text{ seconds}/10 = 2 \text{ seconds}$.

By the way, you may have noticed that, for each pendulum, each successive swing has a slightly smaller ampli-

tude (the amplitude is the distance between one of the extreme positions and the vertical). Yet, for each pendulum, there should have been no noticeable difference in the period of the successive swings.

ITQ 5 Before you performed the experiment, you may well have guessed that a pendulum with a heavier bob would swing more slowly (i.e. have a longer period) than a pendulum of the same length with a lighter bob. Having performed the experiment, you should have come to the conclusion that the period does not depend on the mass. It should have taken your heavy-bob pendulum about the same time to execute 10 swings as it took the light-bob pendulum of the same length. This may well be counter-intuitive, yet it has very important consequences. As you will see in the TV programme associated with this Unit, it enables us to make the bob of a Foucault pendulum (designed to measure the spin of the Earth about its axis of rotation) very heavy, without affecting the pendulum's period. The advantage of this is that it takes a very much longer time for this massive swinging pendulum to come to rest than would be the case with a lighter pendulum.

ITQ 6 Provided that you did not, either deliberately or accidentally, interfere with the swinging of the pendulum, the plane of swing should *not* have changed. Thus you can conclude that the plane of the pendulum's swing is constant, regardless of the rotation of the point from which it is suspended.

ITQ 7 Going through the elliptical orbit in Figure 13a, you should expect the Earth to experience two complete seasonal cycles within one orbital period. There are two positions, 2 and 4, where the separation of the Sun and Earth is least (these would presumably correspond to summer) and two positions, 1 and 3, with maximum separation (winter). Spring would occur between positions 1 and 2, and also between positions 3 and 4, while autumn would occur between 2 and 3, and 4 and 1. The orbit of Figure 13b, which is circular but displaced so that the Sun is not at the centre of the circle, would lead to one cycle of seasons per period. Presumably, position 1 would be winter and position 3 summer, with a gradual change to spring at position 2 and autumn at 4. Either model *could* be correct.

ITQ 8 In and around position 4 in Figure 14a, the observer in Britain would see the Sun all the time. There would be no day–night cycle but continuous daylight. On the other hand, around position 2, Britain would have a long period of continuous darkness (facing away from the Sun). In positions 1 and 3, Britain would experience a regular day–night cycle, but so would all other places all over the Earth. The pattern would be identical everywhere; there would be *no seasonal difference between Britain and Australia*.

Note, incidentally, that the angle at which we draw the Earth's axis of rotation *within the plane of the paper* (i.e. within the plane of the orbit) is irrelevant. For instance,

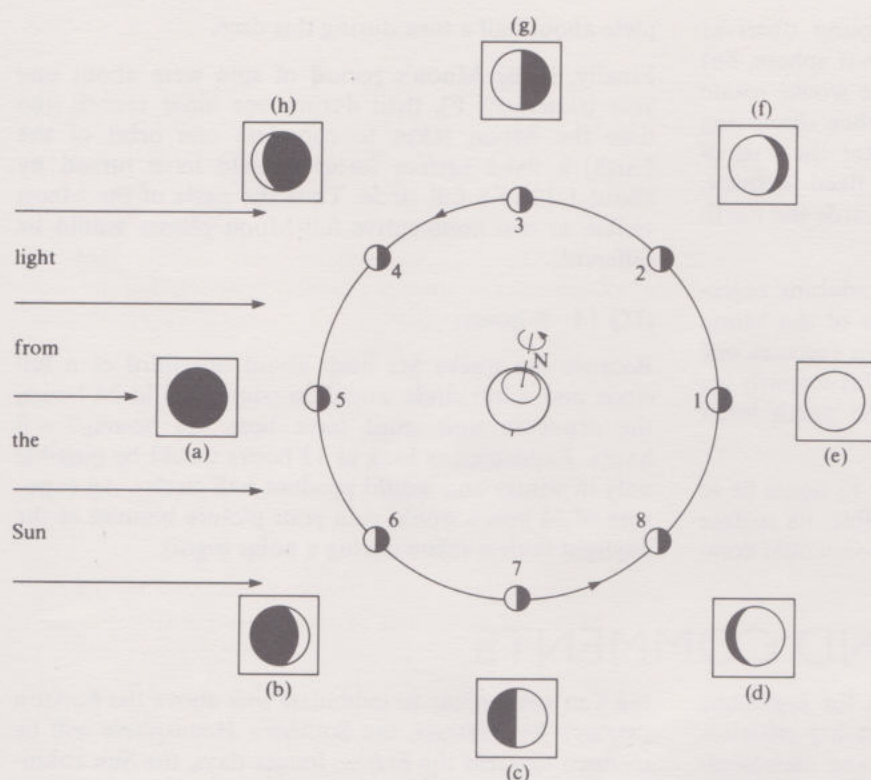


FIGURE 28 Phases of the Moon (for ITQs 10 and 11). Refer to Figure 20 for (a)–(h). Note: If the plane of the lunar orbit were *identical* with the Earth's orbital plane (as assumed in Figure 19), the Moon would be eclipsed *every time* it reached position 1. This does not happen; most of the time we see a fully illuminated Moon (e) at position 1.

had we drawn the axis across the page in all the positions 1 to 4 (rather than up and down the page), this would simply have been equivalent to turning the whole Figure through 90° . Try it!

ITQ 9 Situation 4 in Figure 14a is characterized by the Sun facing the Northern Hemisphere of the Earth. There is an identical relative configuration of the Earth and the Sun in Figure 14b, where the Sun is at the top of the Figure. Similarly for each numbered position in Figure 14a you can find an identical configuration in Figure 14b. Thus, an observer on the Earth could not tell which of the two bodies is orbiting — all observations would be the same in both cases.

ITQ 10 (i) 6; (ii) 1; (iii) 3; (iv) 2.

Perhaps the easiest way to approach this question is as follows. First, you should realize that the lunar hemisphere facing *away from* the Sun (i.e. the right-hand hemisphere in all positions in Figure 19) will always be dark. Try shading this in on Figure 19 before proceeding.

Now you have to imagine what an observer in the Earth's Northern Hemisphere would see when looking directly towards one of the numbered positions of the Moon. You can perhaps help your visualization a bit here by drawing two diverging lines away from the point on the Earth that represents the observer's position, to the extremities of the lunar disc at the orbital position under consideration. If you do this for position 3, for instance, you should be able to convince yourself that the observer sees the right-hand side as dark, i.e. the Moon is in the last quarter. Similarly, for position 6, the observer sees darkness covering almost all of the circle, with only a small crescent of light on the right-hand side *as viewed from the Earth*, i.e. position 6 must

be the waxing crescent. If you had trouble with answering ITQ 10, have another try now at answering (ii) and (iv).

ITQ 11 Using exactly the same sort of 'visualization aids' as in ITQ 10, you should be able to work out that: position 4 is a waning crescent (h); position 5 is the new Moon (a) (eclipsing the Sun); position 7 is the first quarter (c); position 8 is the waxing gibbous phase (d).

All the Moon's phases discussed in this ITQ and in ITQ 10 are shown in Figure 28.

ITQ 12 (i) 7; (ii) 2; (iii) 5; and (iv) 8.

The way to tackle this question is to identify first the position of an observer on Earth experiencing dawn, noon, dusk and midnight. Convince yourself that these experiences correspond, respectively, to an observer looking towards position 3, position 5, position 7, and position 1. Can you now see that if the Moon is in position 3 it will be visible (i.e. above the horizon) from roughly midnight through until noon? Thus, to be visible from noon until midnight (condition (a) in the question), the Moon must be in position 7. Try reasoning out the rest for yourself.

ITQ 13 C and D.

The Moon spins about an axis of rotation which is roughly perpendicular to the plane of the lunar orbit, and with a period of spin exactly equal to the Moon's orbital period. In this way, the changing view of the Moon that we would expect as it circles the Earth would be *exactly* counteracted by the spinning of the Moon around its own axis of rotation.

If statement A were true, the Earth-bound observer *would* always see the same half of the lunar sphere, but all the features away from the lunar pole would rotate in circles. Anyway, as we pointed out when discussing the Foucault pendulum, we would expect the axis of rotation of a freely spinning body to be fixed in space. Here it turns so that it always points towards the Earth — very odd behaviour!

Statement B overcomes the 'Foucault pendulum' objection cited above, but now different faces of the Moon will point towards the Earth as the Moon executes one orbit. That is, the axis of rotation will point towards the Earth only twice in one orbit (once for the 'north' lunar pole, and once for the 'south' one).

If statement E were true, then during the 12 hours or so when the full Moon is continuously visible, its surface features could not remain static. The Moon would com-

plete about half a turn during this time.

Finally, if the Moon's period of spin were about one year (statement F), then during one lunar month (the time the Moon takes to complete one orbit of the Earth) a fixed surface feature would have turned by about 1/12 of a full circle. Thus the parts of the Moon visible at two consecutive full-Moon phases would be different.

ITQ 14 8 hours.

Because the tracks are each about one-third of a full circle and a full circle would be completed in 24 hours, the exposure time must have been $(24 \text{ hours})/3 = 8$ hours. Exposures as long as 12 hours would be possible only in winter and would produce half circles. An exposure of 24 hours would ruin your picture because of the daylight (unless taken during a polar night).

SAQ ANSWERS AND COMMENTS

SAQ 1 Although there is always room for argument, we suggest that, according to the falsifiability criterion, statements (a), (b) and (d) are scientific, and statements (c), (e) and (f) are not.

Statement (a) could conceivably be falsified by production of a white raven, and statement (b) has probably already been falsified by your own experience. This latter example shows that, if the argument of Section 1.2 is accepted, it is quite unnecessary for a scientific statement to be true. Statement (d) could be falsified by interplanetary reconnaissance.

The other statements are not scientific because they contain let-outs that can be appealed to when the statements are not corroborated. With statement (c), a committed believer can always claim that life exists where we have not yet looked; with statement (e), that capitalism's doom, though certain, is not yet come; and with statement (f), that the ceremony cannot have been correctly performed. Notice, however, that all of the three statements that we have classified as not scientific, *could* be true. Indeed, one day, extra-terrestrial life forms may be found, capitalism may be overthrown and the Devil may be conjured up, corroborating the statements; but there is no way they could be *proved false*.

SAQ 2 Your completed Table 3 should be as shown in Table 4.

TABLE 4 For the answer to SAQ 2

Location of observer	Configuration			
	1	2	3	4
Northern Hemisphere	winter	spring	summer	autumn
Southern Hemisphere	summer	autumn	winter	spring

In position 1, the Northern Hemisphere is tilted away from the Sun, so it will receive less light and heat and

the Sun will appear to culminate low above the horizon (winter). By contrast, the Southern Hemisphere will be inclined towards the Sun — longer days, the Sun culminating high above the horizon, more light and heat (summer). In position 3, the relative inclination of the two hemispheres with respect to the Sun is reversed. In positions 2 and 4, both hemispheres go through the transitory mild periods.

SAQ 3 The only thing that matters in the determination of the season is the relative inclination of the hemisphere towards or away from the Sun. Thus position 1 in Figure 15a is the same as position 3 in Figure 15b, where the Sun is to the left of the Earth (Northern Hemisphere tilted away from the Sun — winter). Similarly, a(3) is equivalent to b(1) (summer), a(2) to b(4) (spring), and a(4) to b(2) (autumn).

SAQ 4 The final two items in the Table should be as shown below.

6 Orbital period is one solar year
7 Earth's axis of rotation tilted with respect to the plane of the orbit

SAQ 5 (a) Observations 2 and 3; (b) observations 1, 2, 4 and 7; (c) observations 5 and 9; (d) observations 4 and 6.

All observations 1–9 are consistent with a model that has features (a)–(d). However, some of the observations are particularly relevant to some features. Note that observation 8, although interesting, does not relate to any of the features (a)–(d). It will, however, assume a great significance in Unit 2, when you will be considering the sizes of celestial bodies and their distances from the Earth.

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Figure 1 NASA; Figure 2 Syndication International; Figure 3 Tate Gallery, London.